

ACOUSTICS TECHNOLOGY IN LAND USE PLANNING

VOLUME 1
ANALYSIS OF NOISE IMPACT

JULY 1977



Ontario

Ministry
of the
Environment

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MINISTRY OF THE ENVIRONMENT

ACOUSTICS TECHNOLOGY IN

LAND USE PLANNING

1977

VOLUME 1 - ANALYSIS OF NOISE IMPACTS

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SUBJECT:
ACOUSTICS TECHNOLOGY IN
LAND USE PLANNING

TOPIC: V.I.A.
THE PLANNING PROCESS
IN ONTARIO

OBJECTIVES:

Trainee will be able to:

1. Explain the General Role of the Ministry of the Environment;
 2. Explain the Role of the Ministry of the Environment in the Planning Process;
 3. Define the Term "Environment";
 4. Discuss the Need to Consider Noise During the Planning Process;
 5. Explain the Planning Process in Ontario.
-

V.1.A.1. THE GENERAL ROLE OF THE MINISTRY OF THE ENVIRONMENT

The role of the Ministry of the Environment has been stated as follows:

"Ensure the proper control over the emission of contaminants into the natural environment with the purpose of achieving and/or maintaining predetermined standards of environmental quality; and to ensure the proposed programmes, projects, policies and legislation in or affecting Ontario incorporate the necessary safeguards; and to foster the improved management of the natural environment to achieve a more efficient use of the natural and material resources; and where the above measures are not sufficient, by developing specialized techniques for the restoration and enhancement of environmental quality; and to ensure that proposed programmes, projects, policies and legislation in or affecting Ontario incorporate the necessary safeguards through direct involvement in the coordination and development of a provincial land use plan."

V.1.A.2. THE ROLE OF THE MINISTRY OF THE ENVIRONMENT IN THE PLANNING PROCESS

The above statement embraces all of the Ministry's activities and is given here to indicate the broad range of the Ministry's concerns. More specifically with regard to planning, the Ministry's role may be stated as:

- To ensure that the necessary environmental safeguards are incorporated into land use policies and programmes of all levels of government and the private sector.
- The assessment of environmental management policy alternatives on the basis of constraints imposed by Ontario's socio-economic system, taking into account competing government objectives.



The Environmental Protection Act, 1971

Statutes of Ontario, 1971

Chapter 86

as amended by

1972, Chapter 1, s. 69; 1972, Chapter 106 and 1973, Chapter 94

14.—(1) Notwithstanding any other provision of this Act ^{Prohibition} or the regulations, no person shall deposit, add, emit or discharge a contaminant or cause or permit the deposit, addition, emission or discharge of a contaminant into the natural environment that,

- (a) causes or is likely to cause impairment of the quality of the natural environment for any use that can be made of it;
- (b) causes or is likely to cause injury or damage to property or to plant or animal life;
- (c) causes or is likely to cause harm or material discomfort to any person;
- (d) adversely affects or is likely to adversely affect the health of any person;
- (e) impairs or is likely to impair the safety of any person; or
- (f) renders or is likely to render any property or plant or animal life unfit for use by man. 1972, c. 106, s. 3.

V.1.A.3. DEFINITION OF THE TERM "ENVIRONMENT"

The Ministry is concerned with all aspects of the environment and, therefore, with all aspects of planning that may affect, or be affected by, the environment. To put the Ministry's concerns into proper perspective the definition of environment given in The Environmental Assessment Act, 1975 should be used, which is as follows:

"environment" means:

- (i) air, land or water,
- (ii) plant and animal life, including man,
- (iii) the social, economic and cultural conditions that influence the life of man or a community,
- (iv) any building, structure, machine or other device or thing made by man,
- (v) any solid, liquid, gas, odour, heat, sound, vibration or radiation resulting directly or indirectly from the activities of man, or,
- (vi) any part or combination of the foregoing and the interrelationships between any two or more of them.

V.1.A.4. THE NEED TO CONSIDER NOISE DURING THE PLANNING PROCESS

Noise is usually defined as being unwanted sound. The adverse effects of noise are usually borne by people who were not connected with the noise producing action and receive no benefit from it. The main single source of noise in the urban environment is that stemming from transportation - aircraft, traffic and trains being the main examples. Other noise sources may be large, such as industrial plant, construction projects; or small, such as motorbikes and barking dogs.

Noise is recognized as a pollutant in The Environmental Protection Act, as it can adversely affect many human activities. Speech communications, including television, radio and telephone usage; study or work activity; resting, relaxation and sleep are some examples of interference. As well as causing annoyance due to such activity interference, noise can also adversely affect human efficiency, personal comfort and the enjoyment of property.



Government
of Ontario

The Planning Act

Revised Statutes of Ontario, 1970

Chapter 349

as amended by

1971, Chapter 2; 1972, Chapter 118;
1973, Chapter 168; 1974, Chapter 53;
1975 (2nd Sess.), Chapter 18 and
1976, Chapter 38

and

Ontario Regulation 57/76

35a.—(1) In this section and in section 35b, "redevelopment" means the removal of buildings or structures from land and the construction or erection of other buildings or structures thereon. ^{Interpre-}
^{tation}

(2) Where there is an official plan in effect in a municipality, the council of the municipality in a by-law passed under section 35 may, as a condition of development or redevelopment of land or buildings in the municipality or in any defined area or areas thereof, prohibit or require the provision, maintenance and use of the following facilities and matters or any of them and may regulate the maintenance and use of such facilities and matters: ^{Development}
^{control}

It is clear from these remarks that in order to protect the "health and welfare" (as stated in The Planning Act) of occupants of new homes in Ontario, noise concerns should be given active consideration right from the early stages of a new housing development up to final completion and sale.

V.1.A.5. THE PLANNING PROCESS IN ONTARIO

Under this topic the Planning Process in Ontario will be outlined and the role of the Ministry of the Environment (and the Noise Pollution Control Section of that Ministry) in the planning process will be indicated.

For a more detailed description of the planning process the reader is referred to various other publications on the subject and to the legislation (some of which will be listed later). "Subject to Approval, a Review of Municipal Planning in Ontario", published by The Ontario Economic Council in 1973 provides some information on the planning process and a "Planner's Reference to Legislation in Ontario", issued by the Ministry of Treasury, Economics and Intergovernmental Affairs in 1975, is a reference, by subject, to Provincial legislation that may affect land use planning.

In land use planning, it should always be borne in mind that though elimination, or control of, the source of pollution is usually the primary objective of environmental managers, there are limits to what is practical and technologically possible. This applies to all types of pollution but it is particularly applicable to noise, especially noise from transportation - road, rail and air. Because of the limits to practicality and technology, planners have a share in the responsibility for providing an acceptable level of environmental quality, the planning process being the legal and administrative mechanism for integrating environmental concerns, such as noise, with land use.

V.1.A.5.1. Legislation

Land use planning is generally acknowledged to be the responsibility of the Provinces. In Ontario, however, much of the Provincial authority has been delegated to certain of the Regional Municipalities and to the Municipalities themselves. Legislation setting out the power and responsibilities of these Municipalities are as follows:

The Municipal Act

The various acts establishing the Regional Municipalities

The Planning Act (currently under review)

Other Legislation having a bearing on land use planning is plentiful. Examples are:

The Condominium Act (currently under review)

The Ontario Water Resources Act

The Environmental Assessment Act

The Beach Protection Act

The Pits and Quarries Control Act

The Conservation Authorities Act

The Public Lands Act

The Land Drainage Act

The Expropriations Act

The Planning and Development Act

The Parkway Belt Planning and Development Act

The Niagara Escarpment Planning and Development Act.

There are also a number of Provincial policies and ministerial guidelines which, though they do not have the same force in law as legislation, can influence land use planning; examples of these are: The Design for Development Program, The Agricultural Code of Practice and the Policy Statement on Land Use near Toronto International Airport, Malton, also the anticipated Ontario Government (Cabinet) Policy on freeway noise control.

V.1.A.5.2. The Role of the Federal Government

The Federal Government, though it does not have as direct control as have the provincial governments, can influence land use planning by its legislation, policies and programs on such matters as transportation, agriculture, resource development, taxation, funding, immigration, and land acquisition.

Legislation recently tabled in Parliament will seek to give the Federal Government control over land uses near an airport unless this power is being exercised by the Provincial Government and Municipality concerned.

The location of airports and height restrictions on structures around them, as well as the funding of capital works and other developments and redevelopments are examples of how the Federal Government can influence land use planning.

V.1.A.5.3. The Formulation and Approval of Official Plans

In essence, an Official Plan is a statement of the intent by a Municipality as to how the land within its boundaries is to be used. All of the Acts establishing the Regional Municipalities specifically require that a Regional Official Plan be produced within a prescribed time limit. When the Official Plan is eventually approved by the Minister of Housing, it is binding in that all future zoning by-laws, municipal undertakings and private sector developments must conform to the Official Plan. This can be overcome by writing Official Plans with a considerable amount of flexibility which may weaken the Plan. As a policy document, an Official Plan may be "flexible" since implementing zoning by-laws cannot be flexible. However, where no Official Plan exists unplanned and uncoordinated development often results.

Considerable time and effort goes into the preparation of an Official Plan before it reaches the stage where it can be submitted to the Minister of Housing: Some of the things that may have to be done are: land classification and inventorying, mapping, population projections, analysis of transportation and servicing requirements, consultations with municipal departments, citizen and industrial groups, Provincial and possibly Federal agencies, and conservation authorities. This work may be done by the municipality's planning staff, a consultant engaged for the express purpose, or by a combination of the two. The Noise Pollution Control Section, of the Pollution Control Planning Branch of the Ministry of the Environment is often called upon at this stage in the formulation of the Official Plan. The form of assistance provided is varied but can be in terms of general policy, advising a particular approach for single noise sources or, in some cases, advising on sound level limits to be incorporated into the Official Plan or its Appendices.

When the Official Plan is eventually written in its final form it must be adopted by Council before it may be submitted to the Minister of Housing. The final form of the plan, as submitted, is called a Proposed Official Plan.

Sufficient copies are submitted so that the Ministry of Housing can circulate the Proposed Plan to other Ministries and agencies for their comments. The purpose of this circulation is to identify any conflicts with the policies, programs and objectives of these other ministries and agencies. It also provides an opportunity for the latter to comment on matters of concern to them such as: availability of water and sewage services, hazard lands, drainage, access to highways, air quality, noise, management of solid waste, agricultural land, housing needs and school space.

In the particular case of the Ministry of the Environment, the Proposed Official Plan is usually circulated to the relevant Regional Office. It is then forwarded if necessary, by the Regional Office to the Noise Pollution Control Section and others. Comments on noise are returned to the Regional Office which also collect other comments from the various groups within the Ministry of the Environment and returns a unified response to the Ministry of Housing.

One particular minor exception to the process is a Proposed Official Plan for a Regional Municipality. These are not handled by the Regional Office, MOE, but by the Land Use Coordination and Special Studies Section of the Environmental Approvals Branch in Toronto. They also may request advice with respect to potential noise problems from the Noise Pollution Control Section.

Comments made by the Ministry of the Environment on the Proposed Official Plan, in common with those made by other Ministries and agencies are advisory only. The decision as to whether or not the Official Plan is approved, as submitted or as modified, is made by the Minister of Housing. Modifications may be required or imposed by the Minister as a result of the advice received and the recommendations of his staff. The whole, or part, of a proposed Official Plan may be referred to the Ontario Municipal Board (OMB), by the Minister or Municipality for arbitration. Staff can be subpoenaed to appear as expert witnesses before the Ontario Municipal Board under the powers of The Ontario Municipal Board Act.

V.1.A.5.4. Amendments to the Official Plan

As indicated earlier, Official Plans are the basis for successive and more detailed steps in the municipal planning process. However, due to the changing needs and priorities of certain municipalities, some Amendments to the Official Plan may be deemed necessary after approval of the Plan.

Proposed Amendments to the Official Plan are treated in a similar manner to the original Official Plan, except that they might not be circulated to those Ministries and agencies which the Ministry of Housing consider have no concern with the proposed changes.

On several occasions the Ministry of the Environment has commented unfavourably on proposed Amendments to the Official Plan due to the presence of significant near-by sources of noise. In such cases, recommendations were made to the Ministry of Housing for further investigation of the potential noise problems and noise control measures before the Ministry of the Environment could recommend the proposal for approval. Recommendations were also made that the developer consult with the Noise Pollution Control Section during development of the site to ensure that the final result is an acceptable noise environment on the site.

V.1.A.5.5. Municipal Zoning By-laws

Municipalities may pass Zoning By-laws under The Planning Act covering the use of land, the erection or use of buildings and so on. The Zoning By-law should, of course, conform to the Official Plan if one exists, and could be a more detailed presentation of that Official Plan. The process of approval for a Zoning By-law differs in two respects from the Official Plan Approval Process. First, the By-law is reviewed by the Ministry of Housing and not circulated to other Ministries and agencies; and secondly the By-law must be approved by the Ontario Municipal Board. The Noise Pollution Control Section may again provide assistance directly to the Municipality with regard to portions of the By-law concerned with noise.

V.1.A.5.6. Draft Plans of Subdivision

Draft Plans of Subdivision are submitted by the applicants, which are usually the owners of the land to be subdivided, or their agents, to the Ministry of Housing or to the Regional Municipality in those cases where the approval authority has

been delegated. Prior approval by the local or area municipality in which the lands lie is not mandatory. However, as a matter of prudence most prospective subdividers consult with the local, or area, municipality before formally submitting their applications.

The Ministry of Housing or the Regional Municipality circulates the draft plan to those Ministries and agencies whose advice is required in order to evaluate the draft plan. The local or area municipality is included in this circulation.

As a result of the review by the Ministry of Housing or the Regional Municipality, the draft plan of subdivision may be approved as submitted, approved with conditions, turned down completely or with advice as to how it could be made acceptable.

The review of a draft plan of subdivision includes consideration of: conformance with the Official Plan and Zoning By-laws of the area, health aspects, effect on the educational system, traffic, sewage treatment, water supply, drainage, effect on quality of subsurface water or nearby streams or lakes, air quality, noise, or any other relevant matter. However, the chief concern is the health, safety, convenience and welfare of the future inhabitants.

As with Proposed Official Plans, the Regional Offices act as coordinators of comments with regard to Draft Plans of Subdivision. In the case of potential noise problems, copies of the Plans are forwarded to the Noise Pollution Control Section who attempt to do a rapid appraisal of the situation, using prediction techniques wherever possible. The reply to the Regional Office is usually in the form of a standardized initial comment describing the magnitude of the noise problem on the subject site. If necessary, it is also recommended that the developer maintain close contact with the Noise Pollution Control Section in order to discuss and agree upon the noise control measures required to reduce noise levels on the site to acceptable levels.

The concerns of the Ministry of Housing and/or the Ministries and agencies can be provided for in the conditions of draft approval. In the case of an adverse comment involving noise, it is very often made a Condition of Draft Approval that the

developer supply an undertaking to incorporate acceptable noise control measures on the site. The place for making such an undertaking is the Subdividers Agreement, entered into between the developer and the Municipality, where noise control measures can be specified in detail.

V.1.A.5.7. The Subdividers Agreement and Final Approval

The Subdividers Agreement is an agreement made by a developer with the Municipality to provide certain things on the site such as provision of sodding, lighting etc. As well as specifying financial arrangements, the Subdividers Agreement is an ideal place to obtain a legally binding undertaking from the developer to institute suitable noise control measures. While drawing up the Agreement, informal discussions are frequently held between the developer and the Ministry of the Environment. Often the Municipality, the developer's consultants and lawyers, and representatives of the Ministry of Housing and the Regional Office of the Ministry of the Environment attend these meetings.

Once detailed noise control measures are agreed upon, the Regional Office is informed of the required control measures in detail. Once they see these measures included in the Subdividers Agreement, they can recommend to the Ministry of Housing (or the Regional Municipality) that the Plan of Subdivision be given final approval from the noise aspect.

V.1.A.5.8. Building Permits

It may happen that detailed noise control measures cannot be included in the Subdividers Agreement. One reason for this may be that no detailed plans or specifications are available for the residential (or commercial and office) buildings themselves. In this case it is often possible to include a clause in the Subdividers Agreement which states that the developer understands that Building Permits (which are issued by the Municipality for the individual Units) will not be issued until the Ministry of the Environment is satisfied that adequate noise control measures will be incorporated in the site layout and the individual building Units on the site, as necessary.

V.1.B.5.9. The Condominium Act

An evident exception to the process given above is the construction of condominiums under The Condominium Act. If the subject land is suitably zoned for development (usually medium or high density residential, although some single family residential developments have appeared as condominiums), then Building Permits are issued by the Municipality and construction commences. Only after at least the foundations are in, does the developer submit his plans for Draft Approval under The Condominium Act. In many cases before Draft Approval is obtained the Units are completed and sometimes occupied (not sold, however, as they cannot be sold until the project has been finally approved and registered). This often makes the inclusion of "after the fact" physical noise control measures difficult and in some cases impossible.

Although it has never been done for noise alone, the Ministry of the Environment has recommended against Final Approval for a condominium project and the Units have remained as rental property. This, of course, does not improve the noise situation. The only way to include some form of environmental review early in the life of condominium projects is by liaising with the Municipality prior to Building Permit issuance, or if the development requires an Official Plan Amendment, advising the inclusion of noise control measures at that stage.

The Condominium Act is presently under review and it is hoped that, in future, all necessary Approvals will be required to be cleared long before any construction commences.

SUBJECT:
ACOUSTICS TECHNOLOGY IN
LAND USE PLANNING

TOPIC: V.I.B.
ACOUSTICS

OBJECTIVES:

Trainee will be able to:

1. Describe the behaviour and nature of sound waves;
 2. Define relationship between frequency, wavelength and speed of sound;
 3. Distinguish between spherical and cylindrical wave propagation and give examples;
 4. Define decibel, sound pressure level, sound power level and relationships between them;
 5. Give the reasons for the use of logarithmic scale in sound measurements;
 6. Indicate typical sound levels of some common noise sources in decibels;
 7. Combine sound pressure levels due to individual sources into a composite level.
-

V.1.B.1. GENERAL DESCRIPTION OF THE NATURE OF SOUND WAVES AND THEIR BEHAVIOUR

(a) What is Sound?

If a person claps his hands, or strikes a hammer, or plays the violin, sound is produced. The same sound can be heard by another person standing nearby. Sound is a disturbance which travels or propagates in the form of waves similar to waves in water, the disturbance originating with some surface made to vibrate.

(b) How Does Sound Travel?

For the sound to travel or propagate, the surface must be in contact with a material medium such as air, water, or a solid. Sound cannot propagate in vacuum.

(c) Sound Waves

A familiar sight is waves travelling across the surface of water. The action of the water particles is simply to bob up and down like a cork, and not to move with the wave. In sound waves, the particles of the medium simply oscillate to and fro in the direction of the wave, but again do not actually travel with the wave. The energy in the wave is handed on to more distant parts of the medium by a "chain" reaction.

(d) Sound and Pressure

Consider a loudspeaker generating sound. It does so by the to and fro motion of a diaphragm which in turn transmits this motion to the air adjacent to it. This results in small fluctuations in air pressure which travel outwards. These fluctuations in pressure are picked up by the ear as sound. Note that this pressure fluctuation due to sound is superimposed on the normally existing barometric pressure. The additional pressure due to loud sound is very small compared with the normal barometric pressure.

This to and fro motion causes alternate compression and expansion of the air. These pressure fluctuations are sensed by the ear as sound.

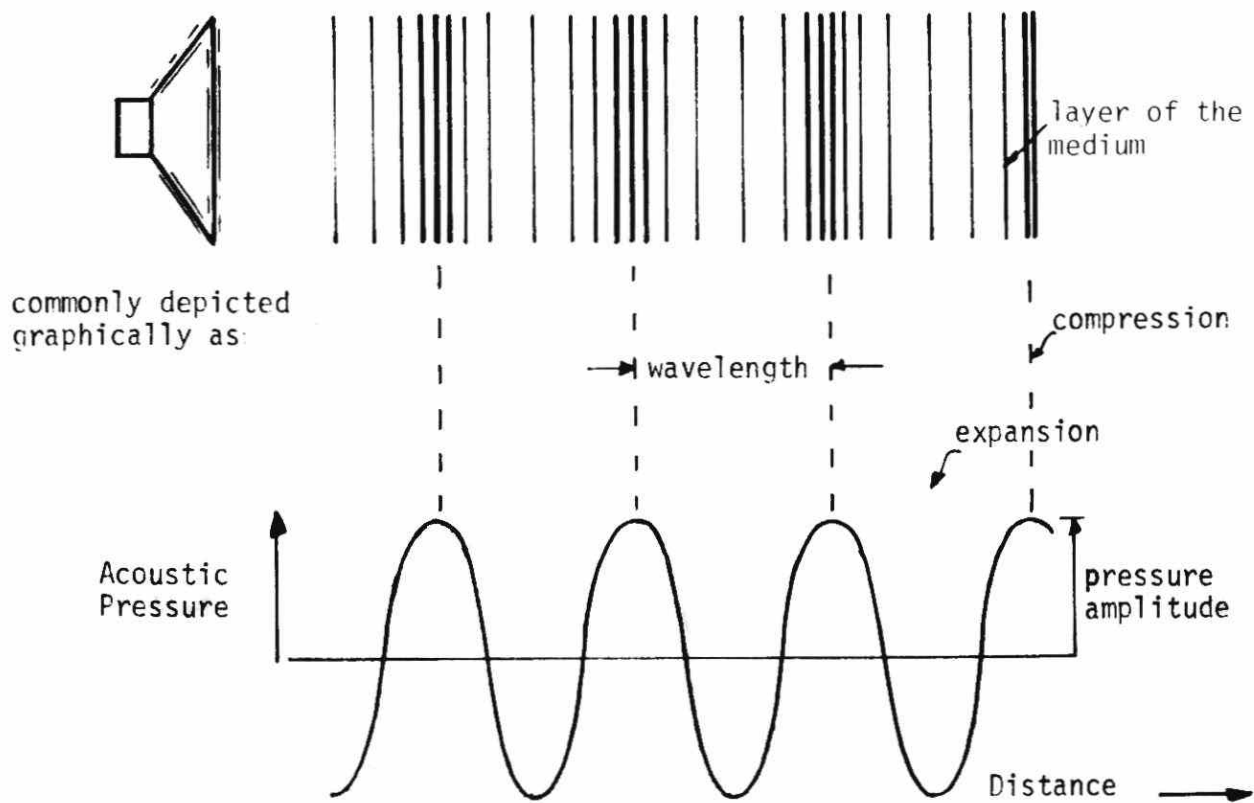


Figure V.1.B.1. Generation of Sound Waves

(e) Speed of Sound in Air

Sound waves do not travel instantaneously. Their speed depends on the medium through which they travel. The speed of sound in air is related to atmospheric temperature, and at 20°C the speed of sound in air is approximately 344 metres per second (1128 feet per second).

EXAMPLE:

Although lightning and thunder are generated simultaneously during a thunderstorm, the observer first notices the lightning and only later hears the thunder. The delay is caused by the time needed for the sound to travel from the thunderstorm location to the observer. (The light due to the lightning can be considered to travel the distance almost instantaneously).

V.1.B.2. RELATIONSHIP OF FREQUENCY, WAVELENGTH AND SPEED OF SOUND

(a) What is Frequency?

Consider the earlier example of the loudspeaker (refer to the Figure V.1.B.1.). When the diaphragm of the loudspeaker moves to and fro, this generates pressure fluctuations in the air adjacent to it in the form of sound waves.

The number of times every second the air experiences these pulsations or fluctuations is known as the "frequency of the sound waves."

Obviously, the frequency of the sound waves generated is the same as the frequency at which the diaphragm moves to and fro.

(b) Units of Measurement of Frequency:

The frequency of sound waves is expressed in "Cycles per Second". Cycles, in this case, refer to the pulsations of the air due to sound waves. In noise control work, a more commonly used unit is hertz (abbreviated as Hz).

"Cycles per Second" and "Hertz" are the same.

EXAMPLE

If the loudspeaker diaphragm moves to and fro 125 times every second continuously, the frequency of sound waves thus generated will be 125 cycles per second or 125 Hz.

(c) Importance of Sound Frequency:

All sounds can be related in terms of frequencies.

Generally, most of the every day sounds are a mixture of different frequencies, and the human ear is capable of detecting sounds in the approximate frequency range 15 Hz to 15000 Hz (or 15 KHz). The ear's sensitivity is not uniform or 'flat' over this range, the sensitivity reducing rapidly at the extremes of the frequency range. The sensitivity of the ear to frequency plays an important role in the noise control field. In noise measurements it has been found useful to highlight certain frequencies and suppress others. For this purpose certain internationally accepted weighting networks have been designed and incorporated in measuring instruments, their function is to simulate electronically the ear's response to sound of different frequencies. The weighting network in most common use in the assessment of environmental noise is the 'A' network. Results obtained with this network are quoted in dBA and are referred to as A-weighted decibels.

(d) What is Wavelength?

The distance between two successive waves is defined as the wavelength. When we talk about the wavelength of a sound wave, we refer to the distance between two successive points, where either the compression or the expansion is maximum (also indicated on the diagram, Figure V.1.B.1.). Wavelength is not usually directly measured but can be determined as shown in the following section.

(e) How to Determine Wavelength:

Wavelength can be worked out from a knowledge of the frequency and the speed of the sound. It is given by the following relationship,

$$\text{wavelength} = \frac{\text{speed of the sound}}{\text{frequency}} \quad \dots(\text{V.1.B.1.})$$

(f) Units of Measurement of Wavelength:

If the speed of sound is expressed in metres per second, and the frequency in hertz, the wavelength will be in metres.

If the speed of sound is expressed in feet per second and the frequency in hertz, the wavelength will be in feet.

EXAMPLES:

In air, the speed of sound at 20°C is 344 metres/sec.
(1128 ft./sec.)

For a frequency of 100 Hz;

$$\text{wavelength in metres} = \frac{344}{100} = 3.44 \text{ metres.}$$

$$\text{wavelength in feet} = \frac{1128}{100} = 11.28 \text{ ft.} \longrightarrow$$

For a frequency of 500 Hz;

$$\begin{aligned} \text{wavelength in metres} &= \frac{344}{500} = 0.688 \text{ metres} \\ &= 68.8 \text{ cms.} \end{aligned}$$

$$\begin{aligned} \text{wavelength in feet} &= \frac{1128}{500} = 2.256 \text{ ft.} \longrightarrow \\ &= 27.1 \text{ inches} \end{aligned}$$

It is to be noted that the sound frequency increases as wavelength decreases.

(g) Importance of Wavelength:

When measuring sounds in the immediate vicinity of sound sources outdoors, a knowledge of wavelength helps in selecting the best measurement locations. The distance between measurement location and the source should ideally be much larger than the wavelength corresponding to the frequency of interest. At the other extreme, high frequency sound (having a short wavelength) is not directly measurable when the diameter of the microphone exceeds the wavelength of the sound. The latter is an example of diffraction of sound, that ability of sound to "bend" around obstacles. The amount of this bending is again related to wavelength, bending increasing with wavelength. This subject is treated in Topic V.2.C., Barrier Calculations.

V.1.B.3. SPHERICAL AND CYLINDRICAL WAVES

As explained in the previous sections, sound travels in the form of waves. There are basically three types of sound waves: (a) Spherical, (b) Cylindrical, (c) Plane.

The type of wave generated depends upon the sound source. The sound waves from a loudspeaker at a distance of about 50 feet will be of the spherical type. On the other hand, when we think of the noise from freely flowing traffic on a highway, the noise comes from a very large number of (moving) point sources. It can be shown that the sound from a whole string of point sources gives rise to waves which spread in a cylindrical fashion, the line, or string of sources, being the axis of the cylinder. At very large distances from a source (very large in comparison to the size of source) spherical waves are very similar to plane waves and may be considered as such.

V.1.B.4. USE OF LOGARITHMIC SCALE IN SOUND MEASUREMENTS

(a) Range of Values:

The ear can respond to an amazingly wide range of acoustic pressures. In everyday life we may encounter acoustic pressures such as generated by rustling leaves, and the acoustic pressures of a roaring jet engine. The acoustic pressure of the latter example may be 1 million times that of the former. In between these two extremes lie all the familiar sounds of modern life e.g. traffic, music, birdsong and roadworks etc.

While we have discussed acoustic pressure and the response of the ear to it, experience has shown that the square of the pressure is a fundamentally more useful quantity in assessing the magnitudes of sounds. The major reason for this is that the square of the pressure as measured at an observer is related to the acoustic power of the noise source. The acoustic power of a source is the basic acoustical characteristic of the source.

(b) Decibel Definitions:

Another reason for adopting "pressure squared" term is that this naturally leads to the use of the decibel scale of measurement. The decibel scale is widely used in various branches of electronics and acoustics. The decibel scale is a power scale and gives a comparison between power related quantities. When quantities are compared using the decibel scale, the comparison is referred to as a LEVEL.

DEFINITION

The Sound Power Level (PWL), or L_W , of a noise source is defined as:

$$L_W = 10 \log \left(\frac{W}{W_{ref}} \right) \quad \text{dB}$$

where, W = the acoustic power output of the source, in watts, and, W_{ref} = the standard reference power of 10^{-12} watts. In all likelihood W will be greater than the very minute value chosen for W_{ref} and so all sound power levels will be a positive number of dB's.

Also, the square of the acoustic pressure is related to the acoustic power output so we may now define Sound Pressure Level (SPL), or L_p , at some observer, as;

$$L_p = 10 \log \frac{(p)^2}{(P_{ref})^2} \quad \text{dB} \quad \dots\dots(V.1.B.2.)$$

where, p = acoustic pressure of the sound waves, in microPascals, μPa and, p_{ref} = the standard reference pressure of $20 \mu\text{Pa}$.

(c) The Relationship between Sound Pressure Level and Sound Power Level :

As we have already learned, the Sound Power Level (PWL) is a measure in decibels of the sound power output by a source. This sound power will radiate away from the source in all directions. As the sound waves travel away from the source the pressure fluctuations must decrease because the available sound power is being spread over a larger area. A similar situation exists when a balloon is being blown up. The bigger the balloon becomes the more the rubber is obliged to stretch and the thinner it becomes. The sound pressure fluctuations are "diminished" and reduced in a similar manner as the available sound power is spread over a larger and larger surface area. The sound power output itself remains constant whatever the distance from the source. The sound pressure fluctuations decrease according to the area over which the available sound power has been spread. Thus the relationship between the Sound Pressure Level, L_p , and the Sound Power Level, L_W , can be expressed as follows:

$$L_p = L_W - 10 \log S \quad \text{.....(V.1.B.4.)}$$

where, S is the total surface area in metres², over which the sound power is spread.

We can now take this equation further for the two main types of source.

(i) The point source :

A point source can be imagined as being a point suspended in air radiating sound equally in all directions. Let us consider an observer at a distance r (metres) from this point source of sound power W , with no reflecting surfaces present.

First, $S = 4\pi r^2$ (i.e. the area of a sphere of radius r)
Let us also consider the effect of increasing r on the Sound Pressure Level.

Let L_{p_1} be the Sound Pressure Level at distance r_1

and L_{p_2} be the Sound Pressure Level at distance r_2 ,

$$\text{then, } L_{p_1} = L_W - 10 \log 4\pi r_1^2$$

$$\text{and, } L_{p_2} = L_W - 10 \log 4\pi r_2^2$$

$$L_{p_2} - L_{p_1} = 10 \log \frac{4\pi r_1^2}{4\pi r_2^2}$$

$$\begin{aligned} \text{Thus for a point source } L_{p_2} - L_{p_1} \\ = 10 \log \left(\frac{r_1^2}{r_2^2} \right) \end{aligned}$$

$$L_{p_2} - L_{p_1} = 20 \log \left(\frac{r_1}{r_2} \right) \quad \dots\dots\dots (\text{V.I.B.5.})$$

From this equation it can be seen that if the distance from a point source is doubled, the Sound Pressure Level is reduced by 6 dB.

(ii) The line source

A line source can be imagined as an infinitely long line suspended in the air radiating sound equally in all radial directions. A similar procedure can be followed as for a point source to obtain the relationship between Sound Power Level and Sound Pressure Level for a line source. However, this involves integration techniques and will not be considered here. Only the effect of increasing r on Sound Pressure Level will be considered.

Again let L_{p_1} be the Sound Pressure Level at distance r_1

and L_{p_2} be the Sound Pressure Level at distance r_2

Thus, for a line source

$$L_{p_2} - L_{p_1} = 10 \log \left(\frac{r_1}{r_2} \right) \quad \dots\dots(\text{V.I.B. 6.})$$

From this equation it can be seen that if the distance from a line source is doubled the Sound Pressure Level is reduced by 3 dB.

EXAMPLE :

A sound level of 65 dB was measured 10 metres distance from a line source. The sound level at 30 metres is required.

Let $L_{p_1} = 65$ dB measured at $r_1 = 10$ m.,

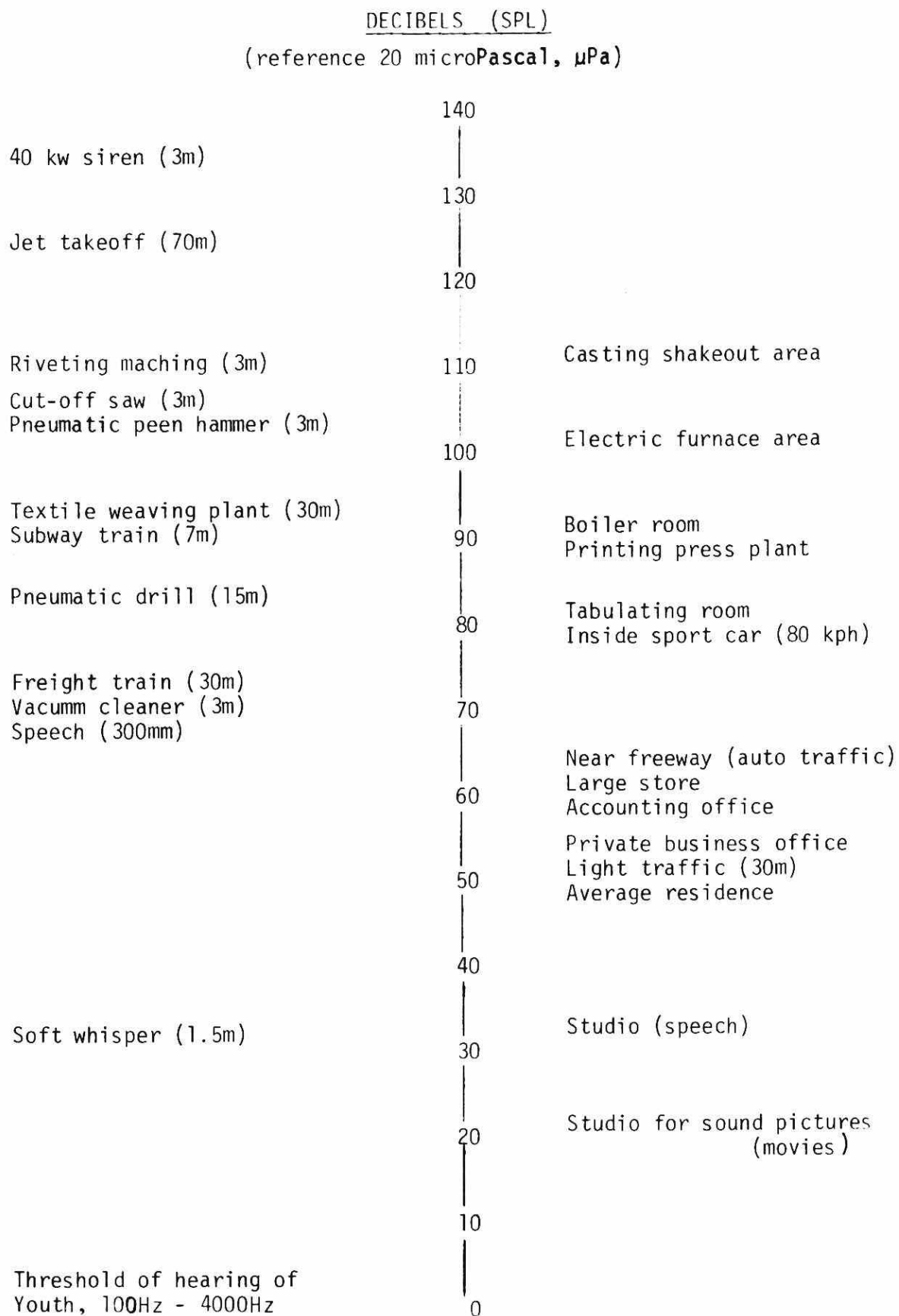
then from Equation V.1.B.5. (for a line source)

$$\begin{aligned} L_{p_2} - L_{p_1} &= 10 \log \left(\frac{r_1}{r_2} \right) \\ &= 10 \log \left(\frac{10}{30} \right) \\ &= -4.8 \text{ dB} \\ L_{p_2} &= 65 - 4.8 \\ &= 60.2 \text{ dB} \longrightarrow \end{aligned}$$

So in retreating from 10 metres to 30 metres from the line source the sound level can be expected to fall to 60 dB.

V.1.B.5. REASONS FOR USING THE DECIBEL SCALE IN SOUND MEASUREMENTS

- (i) We have mentioned that the decibel scale is used in electronics and acoustics for the measurement of power related quantities.
- (ii) Another advantage of the decibel scale is quickly seen when we substitute the values of pressure range 10^6 to 1, the whole range is reduced from 120 dB to 0 dB respectively. So the unwieldy numbers which would result from using a linear pressure scale have been superceded by a scale of numbers which are much more familiar to us.
- (iii) Another feature of the scale is that for each and every tenfold increase in power, the SPL at an observer increases by 10 dB. If we should increase the power output from 10^{-12} w to 10^{-11} w or from 1w to 10w we would, in each case, get an increase of 10 dB. Although the actual change or absolute change in power output in the two cases is quite different, we get the same change in decibels. This is actually of value because if we listened to these changes in level, approximately the same subjective



The sound levels are at the given distance from sound sources

Figure V.1.B.2.: Typical Sound Levels in Decibels (A-weighted)

response would be obtained - we would say that in each case the noise had doubled in loudness from its former value! That is, the increase in loudness appears the same (and is 10 dB).

- (iv) Later in this course we will meet configurations of materials or designs which will effectively reduce (attenuate), or increase (amplify), acoustic power by certain factors. For example, we can expect brick walls to attenuate power incident upon the wall such that only 1/100,000 of the incident power is transmitted. On a linear scale we would have to divide the incident power by 100,000 to obtain the transmitted power. On the other hand, when dealing in decibels, we would say the wall introduces a transmission loss of 50 dB ($=10 \log 100,000$) and subtract from the incident sound pressure level 50 dB to get the transmitted sound pressure level. Similarly for amplification, instead of multiplying power by certain factors, all we need do is add terms in dB to the first sound pressure level in dB.

V.1.B.6. TYPICAL LEVELS OF SOME COMMON NOISE SOURCES

The Figures V.1.B.2. and V.1.B.3. show the sound pressure level and the sound power level respectively at noted distances for various types of common noise sources.

Sound pressure levels defined above may be conveniently measured with an instrument called a Sound Level Meter. However, as remarked in V.1.B.2. the response of the ear is not "flat" with frequency and so an electronic network is used to simulate the ear's response. The network which is most commonly used in environmental acoustics is the 'A' network giving an A-weighting to the noise. Measurements of noise conditioned by the A-weighting are termed Sound Levels and values are quoted in dBA. (If Sound Pressure Levels are taken with "flat" or "Linear" response the values are quoted in dB).

V.1.B.7. ADDING SOUND PRESSURE LEVELS IN DECIBELS

Anyone who has listened to a stereo knows that two speakers do not sound twice as loud as a single speaker. Disconnecting one speaker doesn't reduce the volume very much. This is because the ear hears on a type of decibel scale.

DECIBELS (PWL)
(reference 10^{-12} watt)

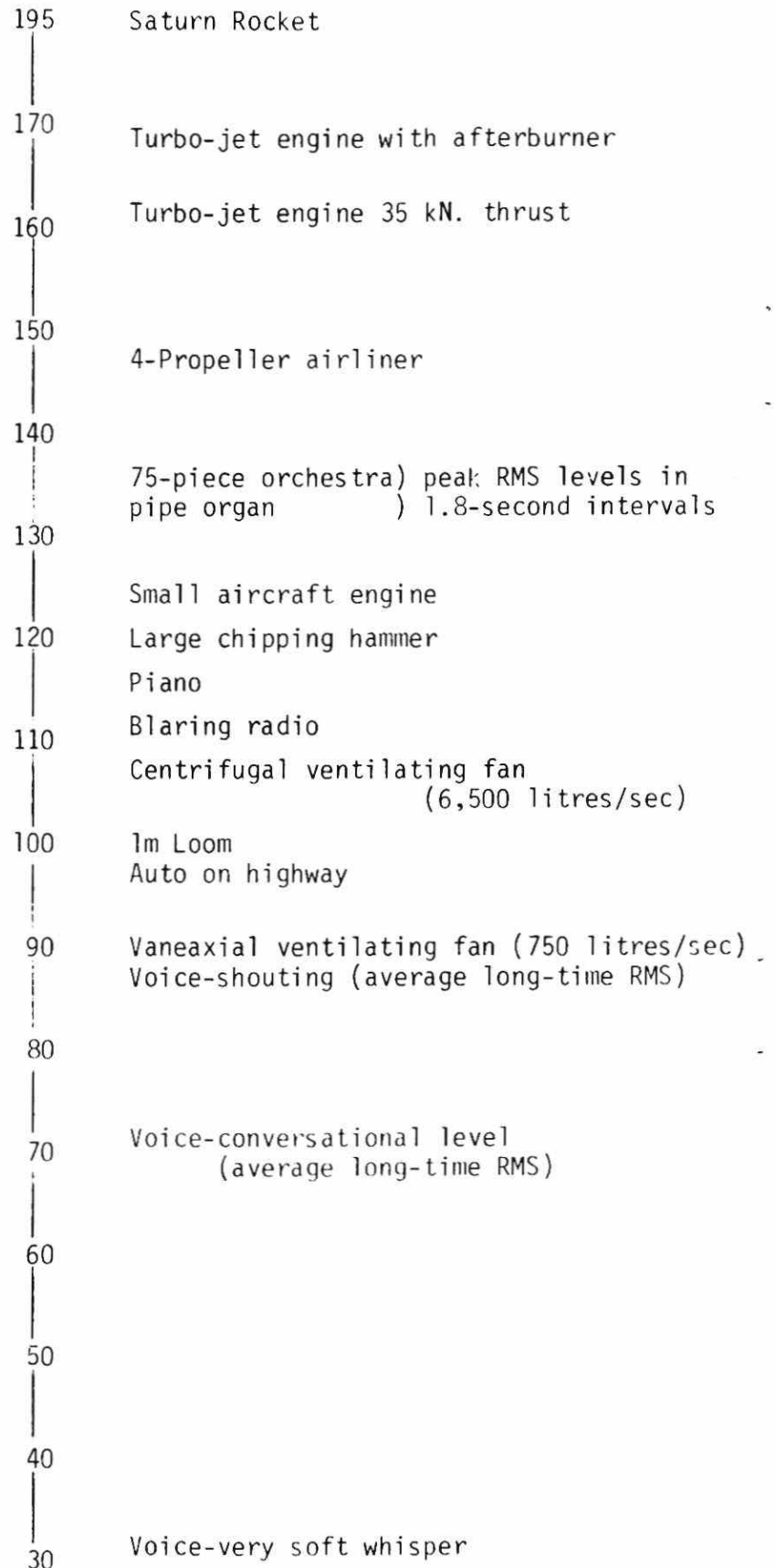


Figure V.1.B.3.: Typical Sound Power Levels (PWL)

(a) How decibels add:

Figure V.1.B.4. can be used to demonstrate how decibels can be added together. Two examples given below illustrate this.

EXAMPLE: - Two equal sounds - add 3 dB.

50 dB & 50 dB equals 53 dB and not 100 dB!

SPL's cannot be added, rather they must be combined.

This is because when sounds from separate sources are received simultaneously, the ear responds to the sum of their individual power contributions and not to the sum of their pressures (or sound pressure levels in dB!).

Therefore, as we are usually given the SPL of each source in turn (in dB), conversion to pressure squared terms must be done first. This involves finding the antilog of one tenth of the SPL. Ten times the logarithm of the sum of such antilog terms gives the resultant SPL of the combined levels. In mathematical notation:

If sound pressure level due to source No. 1 is L_{p_1}

If sound pressure level due to source No. 2 is L_{p_2}

If sound pressure level due to source No. N is L_{p_N}

Then it can be shown that the resultant SPL, L_{p_R} , is;

$$L_{p_R} = 10 \log (\text{antilog } L_{p_1}/10 + \text{antilog } L_{p_2}/10 + \dots + \text{antilog } L_{p_N}/10) \dots (\text{V.1.B.7.})$$

This expression may be used to combine the SPL's due to two, or more, sources etc.

(b) Addition of decibels - nomograph method:

The nomograph given in Figure V.1.B.4. provides a quick, simple and practical method for combining pairs of decibels.

The steps involved are outlined below:

Step 1: take the difference in decibels between the two levels which are being added together.

Step 2: enter this difference on the chart at the right hand side of the scale, and look up the corresponding number on the left hand side of the scale.

Step 3: add the number so obtained to the higher sound level (louder sound of the two).

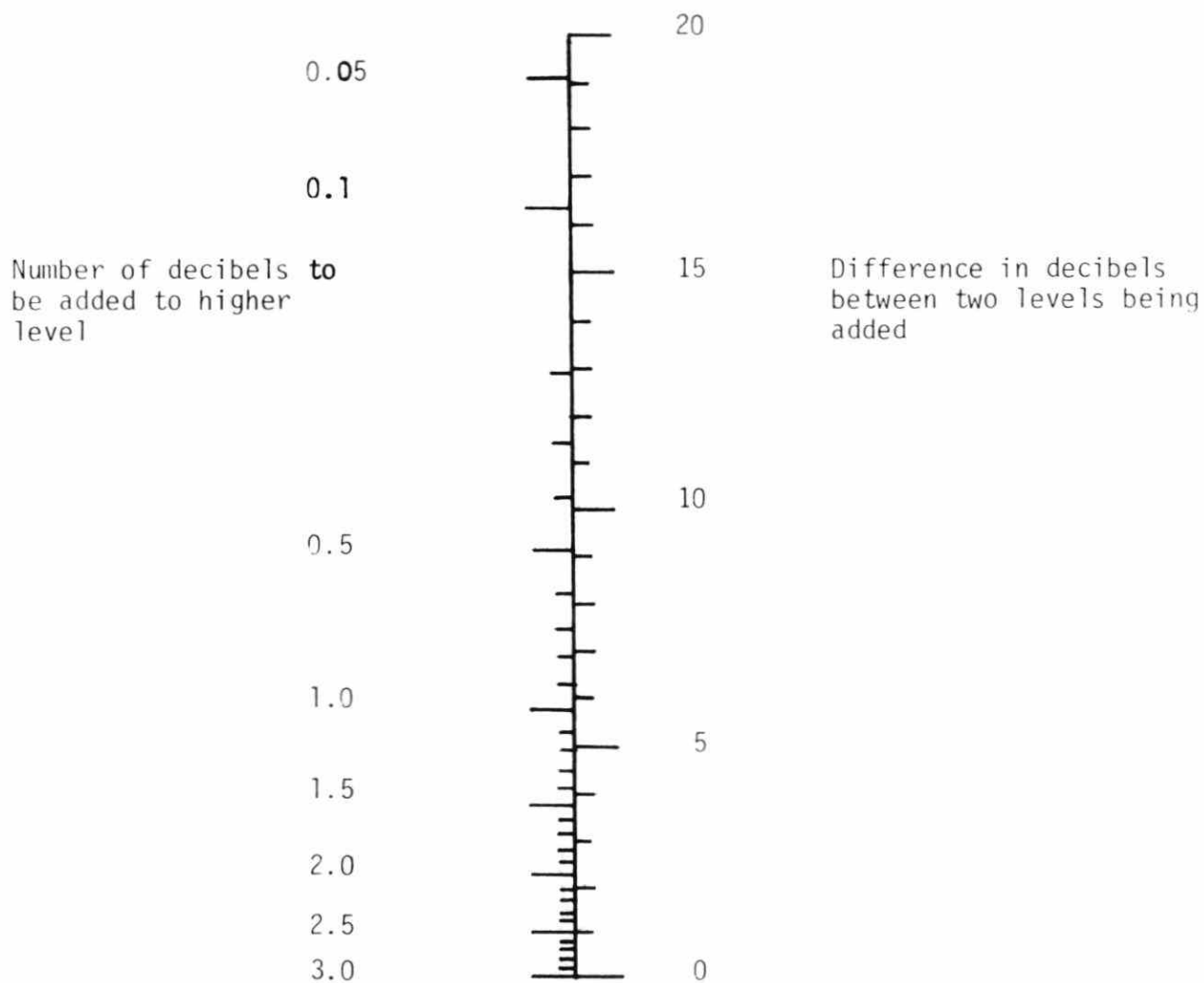


Figure V.1.B.4.: Nomograph for adding sound pressures in decibels

Should more than two SPLs need to be combined, then any two levels can be replaced in the summation by their equivalent found by the combination process.

EXAMPLE:

Find the resultant of the following sound pressure levels
60 dB, 54 dB, 65 dB.

Consider first 60 dB and 54 dB.

Step 1: The difference is 6 dB.

2: from the chart the corresponding number is
about 1 dB.

3: adding 1 to the higher SPL we get 61 dB. —→

So the result of combining 60 dB and 54 dB is 61 dB.

Consider now combining 61 dB (i.e. 60 dB & 54 dB)
and 65 dB.

Step 1: The difference is 4 dB.

2: from the chart the corresponding number is
about 1.5 dB.

3: adding 1.5 dB to the higher we get 66.5 dB. —→

So the effective SPL due to the three individual
SPLs is 66.5 dB.

Should the sequence in which the SPLs are combined be
changed, the identical result would be obtained.

Note from the nomograph method:

- (i) two levels will not result in more than 3 dB adjustment
to the higher level.
- (ii) when two levels are more than 10 dB different, their
resultant SPL is less than 0.5 dB greater than the
higher of the two levels.
- (iii) Very roughly, for quick calculations, you may use:

difference between two levels, dB	add to higher level, dB
0	3
2	2
6	1
10	0

which can be memorized, and interpolations made by constructing
a graph.

(c) Accuracy while combining decibels:

At this point it may be pointed out that during most sound measurements, accuracy of better than 0.5 dB is hardly ever attained. Therefore sums that give numbers like 60.1 dB or 101.2 should usually be rounded off to 60 dB and 101 dB respectively. As a general rule, round up for 0.5 dB and above; round down for values below 0.5 dB.

e.g. 60.5 becomes 61 and 60.4 becomes 60. If the sums are part of a longer calculation, the extra digit should be kept until the end of the calculation before it is dropped.

EXAMPLE:

52 dB & 60 dB = 60.6 dB
→ 61 dB (by rounding off)

68 dB & 72 dB = 73.5 dB
→ 74 dB

OBJECTIVES:

Trainee will be able to:

1. Understand the variability of community noise;
 2. Understand the concept of the statistical distribution;
 3. Obtain a cumulative distribution from a statistical distribution;
 4. Define and use L_N , L_{100} , L_{90} , L_{50} , L_{10} , L_1 , and L_0 ;
 5. Understand the concept of the energy equivalent continuous level (L_{eq});
 6. Perform calculations and manipulations with L_{eq} ;
 7. Understand the relationship between L_{eq} and the L_N descriptors.
-

V.1.C.1. THE TIME VARYING NATURE OF COMMUNITY NOISE

Many community noise sources do not produce noise of a steady nature. Noise sources such as traffic, construction sites and radios produce noise levels which are time-varying, often between very wide limits. Unfortunately, a sound level meter is not sufficient to measure such unsteady noises. It is advised that if a sound level meter needle is fluctuating through more than about 3 dB, taking a simple eye average of the fluctuations will be inaccurate and should not be attempted. Clearly, if a noise is varying by more than this amount a regular sound level meter will not be sufficient for assessing the noise source.

In any typical community, the lower noise levels will be present for a major portion of the time and will consist of natural sounds such as leaves rustling, flowing water, bird or animal noises. These noises are often accompanied, or perhaps dominated, by distant traffic noise or steady industrial noise. The next higher noise levels will be present for less time and be composed of such sources as nearby highways and industry. Increasing again in level, and decreasing in duration, local traffic would contribute next to the sound pattern. Trucks and trains could give higher levels but are only present for short periods of time. Sources giving even higher levels are children shouting, dogs barking and even lightning, all of which are fortunately only present for very short periods of time. It is, of course, difficult to generalize the sound level variation with time in a community, but it can be judged from the example given that, as the sound level increases, then it is present for shorter periods of time. This trade-off of level and time duration is generally typical of most community noise situations.

V.1.C.1.1. Range of Variation in Community Noise Levels

To give some idea of the possible variation of community noise levels consider the two extreme situations; in the first case the community is located adjacent to a busy freeway and at all times the noise climate is dominated by the free flowing traffic noises. Typical variation in the community noise level is 10 to 20 dB.

At the other extreme, consider the situation of a community situated close to railway tracks. At night with no trains on the tracks the noise level in the community will be very low, typically 25 to 30 dBA in quiet surroundings. However, as a train passes by the noise levels could increase to some 90 dBA. This gives a sound level range of some 60 dBA. Clearly if measurements are required over this wide range then specialized instrumentation may be required.

V.1.C.1.3. The Limitations of the Sound Level Meter for Community Noise Measurement

It has been stated already that if a sound level meter needle shows a range of deflection greater than 3 dB then a single, eye-average, sound level will not accurately reflect the noise environment and should not be taken. Clearly many community noise situations will produce (even on "Slow") deflection ranges greater than 3 dB, making the sound level meter unsuitable for community noise measurement.

A further problem may occur because of the limited scale range of normal sound level meters. At most a 15-20 dB range is provided for sound level indication without the necessity of changing attenuators. Thus even if a single sound level could reflect the community noise situation, or if a system were devised for using a sound level meter to measure noise, then only sound level variations over this 15 to 20 dB range could be analysed. In fact, a sound level meter can be used for community noise analysis but the limited scale range does restrict the use of the instrument.

V.1.C.1.3. Using a Sound Level Meter to Obtain a Series of Community Noise Measurements

How can the simple sound level meter be used to give an assessment of non-steady community noise? The answer is by taking single sound level measurements at certain regular intervals (say 10, 20 or 30 seconds) over a specified measurement duration. Imagine that a sound level meter was used close to a busy highway, where the variation is only 10-20 dB. Noise levels were taken at exactly 10 sec. intervals for 10 minutes,

making 60 single sound level measurements altogether. The results were taken to the nearest A-weighted decibel and entered into the following chart in Figure V.1.C.1., each asterisk representing one sound level reading.

The chart provides a useful description of the whole variation of the noise level over the ten minute period. The noise level never fell below 65 dBA. The noise level stayed for a long time at 70 dBA, this level probably being associated with individual car passbys.

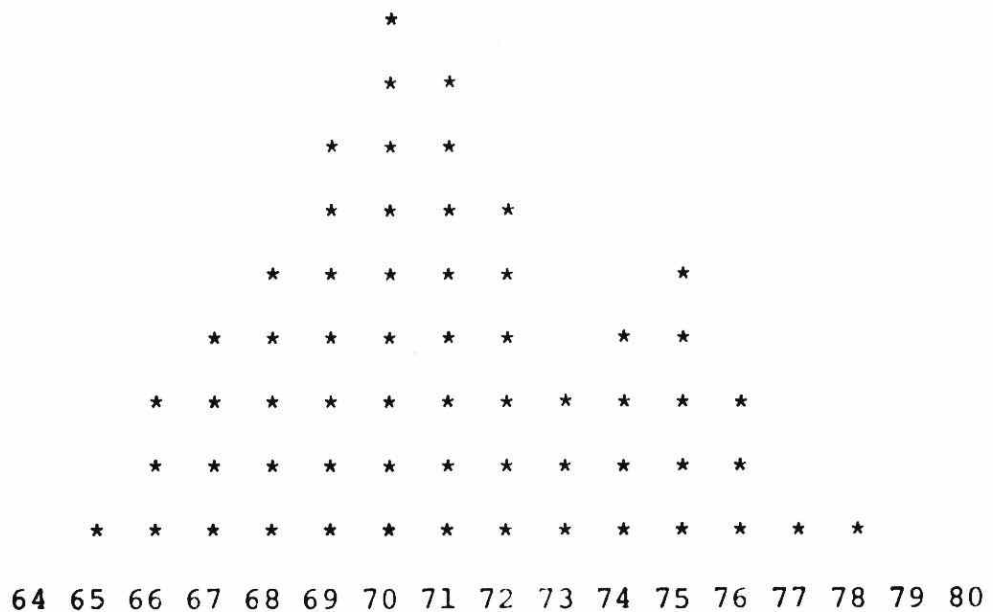


Figure V.1.C.1. Typical Histogram of Sound Level Measurements Adjacent to a Freeway

A second peak occurred at a sound level of 75 dBA which probably represented individual truck passbys, which would be less frequent than the cars, but at a higher noise level. The maximum sound level recorded was 78 dBA. Thus the chart provided a useful picture of the noise variation over the ten minute period. Such a chart is known as a HISTOGRAM, and is a diagrammatic representation of the STATISTICAL DISTRIBUTION of the sound variation during the ten minute measurement period.

In using a sound level meter to measure community noise the following precautions should be taken:

- (a) The measurements should not be tried if short duration, high level, noises are present.
- (b) The meter must be read at the precise instant regularly.
- (c) The period of measurement should be long enough to adequately represent the noise climate.

V.1.C.2. THE STATISTICAL DISTRIBUTION

We have already seen how a time-varying sound level can be described in chart form which indicates for how long the sound remained at a certain level. This method of describing the sound level variation is known as the statistical distribution. In general, however, there are differences from the particular case we have discussed. First of all, the sound varied over only 14 dB whereas the community noise level in many cases will vary over a greater range than this. Taking the readings every dB for wide ranging noise levels results in too large a set of numbers. To avoid this problem, the sound levels are grouped together in certain dB windows. Typically these windows are up to 5 dB in width.

A second difference is that very often we have very much more than 60 readings, perhaps as many as 10,000. These large numbers can be cumbersome. To avoid this difficulty, the number of times the sound was in a certain dBA window is divided by the total number of counts and multiplied by 100 to give a percentage of the total number of counts. Thus the statistical distribution is usually stated as the percentage of the measurement time for which the sound level remained in each of the dBA windows of interest. In all cases in the analysis of community noise levels, the dBA window widths are constant across the sound level range. Very often 5 dB wide windows are used, a total sound level range of 50 dB being divided into 10 windows. An example of such a statistical distribution is shown in Figure V.1.C.2.

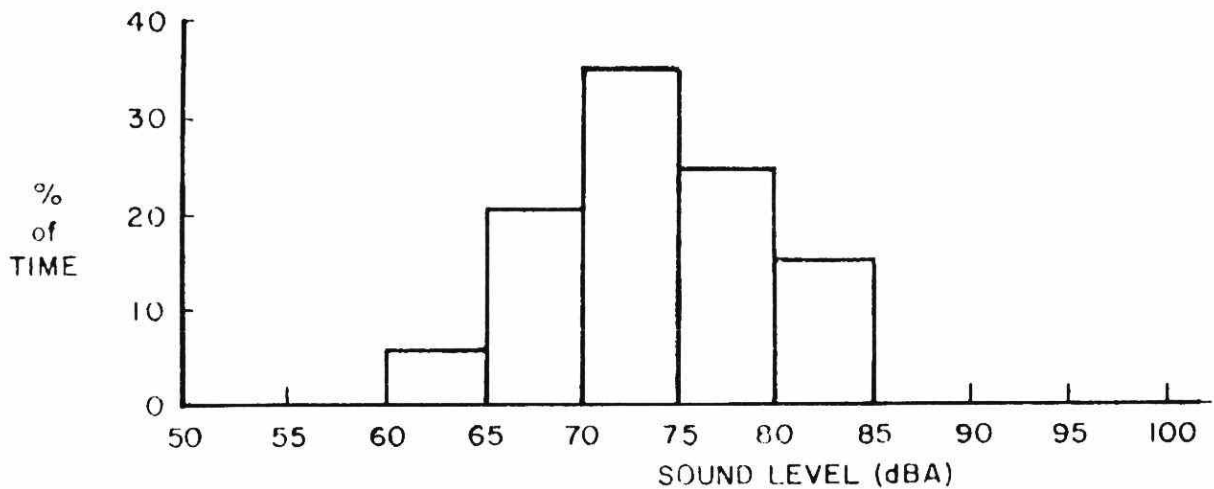


Figure V.1.C.2. A Typical Statistical Distribution Plot

In tabular form, this statistical distribution would appear as follows:

Sound Level Range (dBA)	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100
% of time	0	0	5	20	35	25	15	0	0	0

It should always be checked that the individual percentages add up to 100% as they do in this case.

V.1.C.3. OBTAINING THE CUMULATIVE DISTRIBUTION FROM THE STATISTICAL DISTRIBUTION

Useful though the statistical distribution is as a means of presenting time-varying sound data, it still does not present information in the most convenient form for further consideration or annoyance assessment. The statistical distribution answers the question "for what percentage of the time was the noise level within a certain dBA range?" The cumulative distribution, however, answers the question "for what percentage of the time was a certain noise level exceeded?"

How can the cumulative distribution be derived from the statistical distribution? The best way to do this is by a step by step procedure. By way of example, consider the problem given in Figure V.1.C.2. Starting at the right hand side of the graph, we ask "for what percentage of the time was the level over 85 dBA?" The answer is, of course, 0%. This gives us the first point of the cumulative distribution:

85 dBA, percent of time exceeded 0%

We ask the question again - for what percentage of time was the level of 80 dBA exceeded? Again looking at the diagram, the answer is 15% of the time. Now we have two points on the cumulative distribution:

80 dBA, percent of time exceeded 15%

Continuing with the procedure, the sound level of 75 dBA was exceeded 25 + 15 or 40% of the time giving a third point on the curve. If we continue with this procedure, adding a further dBA range each time we would eventually ask the question: "for what percentage of the time was 60 dBA exceeded?" Adding in the final 5% would give the answer 100% of the time which means that the level was never below 60 dBA. For comparison both the statistical and cumulative distributions are plotted out in Figure V.1.C.3. with the tabular form of both listed below.

STATISTICAL DISTRIBUTION OF NOISE CLIMATE

Sound Level Range (dBA)	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100
% of time	0	0	5	20	35	25	15	0	0	0

CUMULATIVE DISTRIBUTION OF NOISE CLIMATE

Sound Level dBA	50	55	60	65	70	75	80	85	90	95
% of time exceeded	100	100	100	95	75	40	15	0	0	0

Table V.1.C.1. Statistical and Cumulative Distribution in dBA for Freeway Sound Measurements.

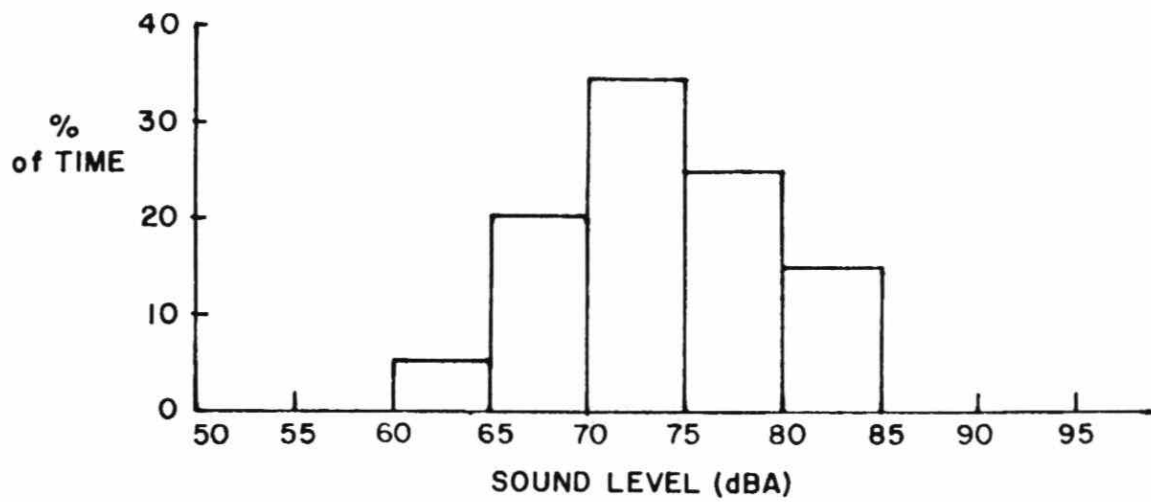
V.1.C.3.1. The Use of Statistical Distribution Paper

The cumulative distribution shown in Figure V.1.C.3. is plotted with a linear percentage scale. A special graph paper (known as statistical distribution paper) exists for plotting such a distribution. It has a non-linear percentage scale and is shown in Figure V.1.C.4. The same cumulative distribution has been plotted on this special paper. Notice first of all the reorientation of the scales and also the strangely non-linear percentage scale.

Why is this percentage scale used? There is a certain statistical distribution known as "Gaussian" or "Normal Distribution". This distribution is well defined theoretically and often many community noise variations result in a Gaussian distribution. If a statistical distribution is, in fact, Gaussian then several simplified calculation formulae may be used. Statistical Distribution paper has a % of time exceeded scale so arranged that if a Gaussian Distribution were plotted on it, then a straight line would result. The statistical distribution shown in Figure V.1.C.3. has also been plotted on the statistical distribution graph paper. It can be seen that in the middle of the paper the graph is approximately a straight line, and could probably be considered as being Gaussian. Thus simplified calculation methods (e.g. the one covered later in topic V.1.C.7.) applying to Gaussian distributions could be used for this distribution.

Statistical distribution paper has the second advantage of spreading out the portion of the cumulative distribution above the 10% exceeded point. This is an important region in acoustics and can be more easily examined using this graph paper.

STATISTICAL DISTRIBUTION



CUMULATIVE DISTRIBUTION

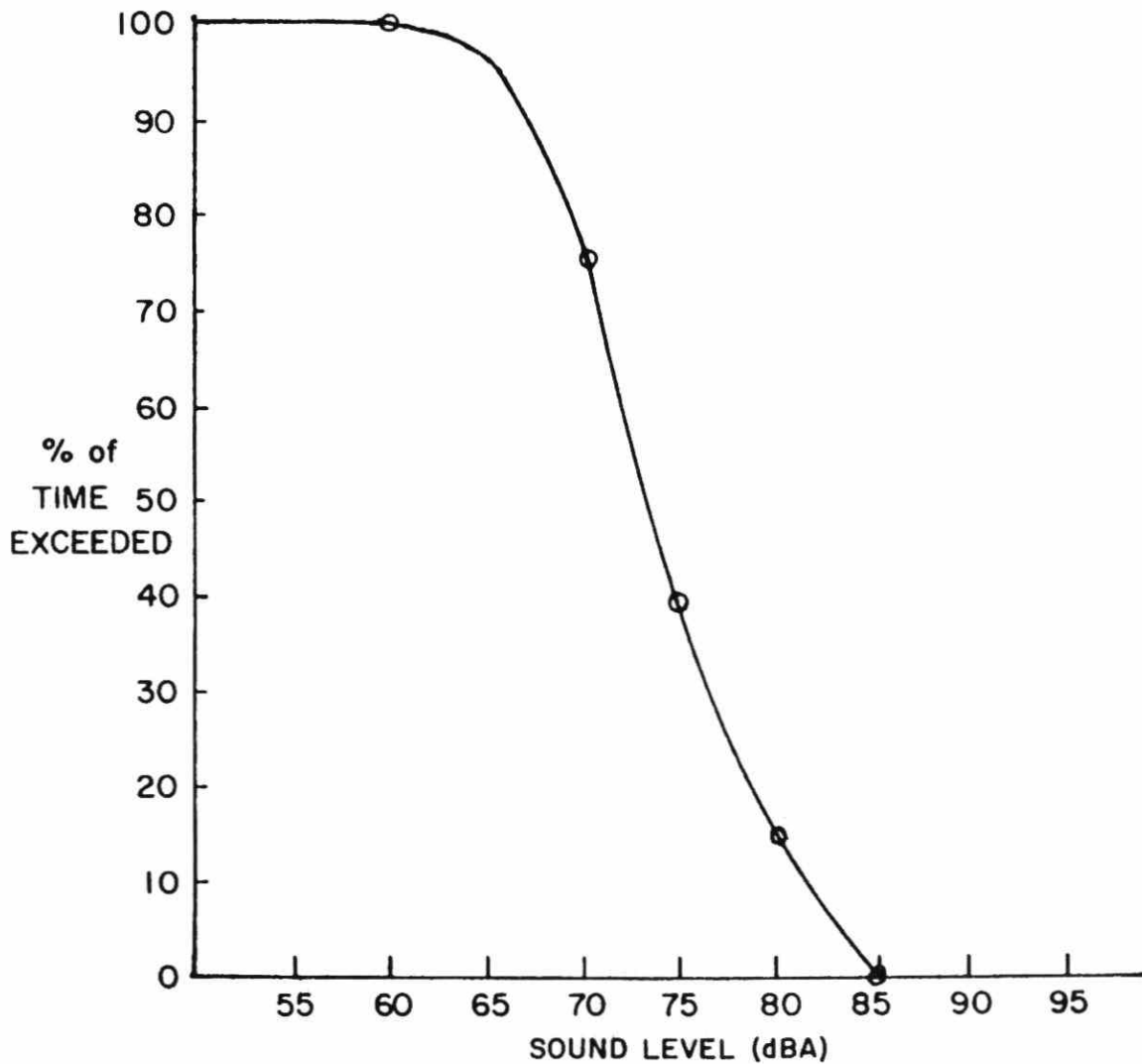


Figure V.1.C.3.: Generation of Cumulative Distribution Plot From Statistical Distribution Plot

V.1.C.4. DEFINITIONS AND USE OF L_N , L_{100} , L_{90} , L_{50} , L_{10} , L_1 , and L_0

We have just seen that a cumulative distribution is a plot of the percentage of time for which certain sound levels were exceeded. In order to extract useful information from the plot, very often the reverse question "what level was exceeded for a certain percentage of the time?" is presented. For instance, it may be required to know from the cumulative distribution (Figure V.1.C.5.) which we are considering, what level was exceeded for 10% of the time? Looking at the plot on statistical distribution paper, we see that the level exceeded for 10% of the time was 81 dBA. Such levels are often known as L_N values, L_N being defined as follows:

- L_N is the level exceeded for N% of the time.

Common L_N values used are as follows;

- L_{100} : the level exceeded for 100% of the time or the lowest noise level.
- L_{90} : the level exceeded for 90% of the time or the "ambient" noise level.
- L_{50} : the level exceeded for 50% of the time or the "median" noise level.
- L_{10} : the level exceeded for 10% of the time, measures the "average level of intrusive" noises.
- L_1 : the level exceeded for 1% of the time, measures the "highly intrusive" noises.
- L_0 : the level exceeded for 0% of the time or the "highest" noise level (also known as L_{MAX}).

V.1.C.4.1. L_{90} , L_{50} , L_{10} , and L_1 From Cumulative Distribution Graph

All these levels have been obtained from the cumulative distribution shown in Figure V.1.C.5.

L_N	Sound Level dBA
L_{100}	60
L_{90}	67
L_{50}	74
L_{10}	81
L_1	84
L_0	85

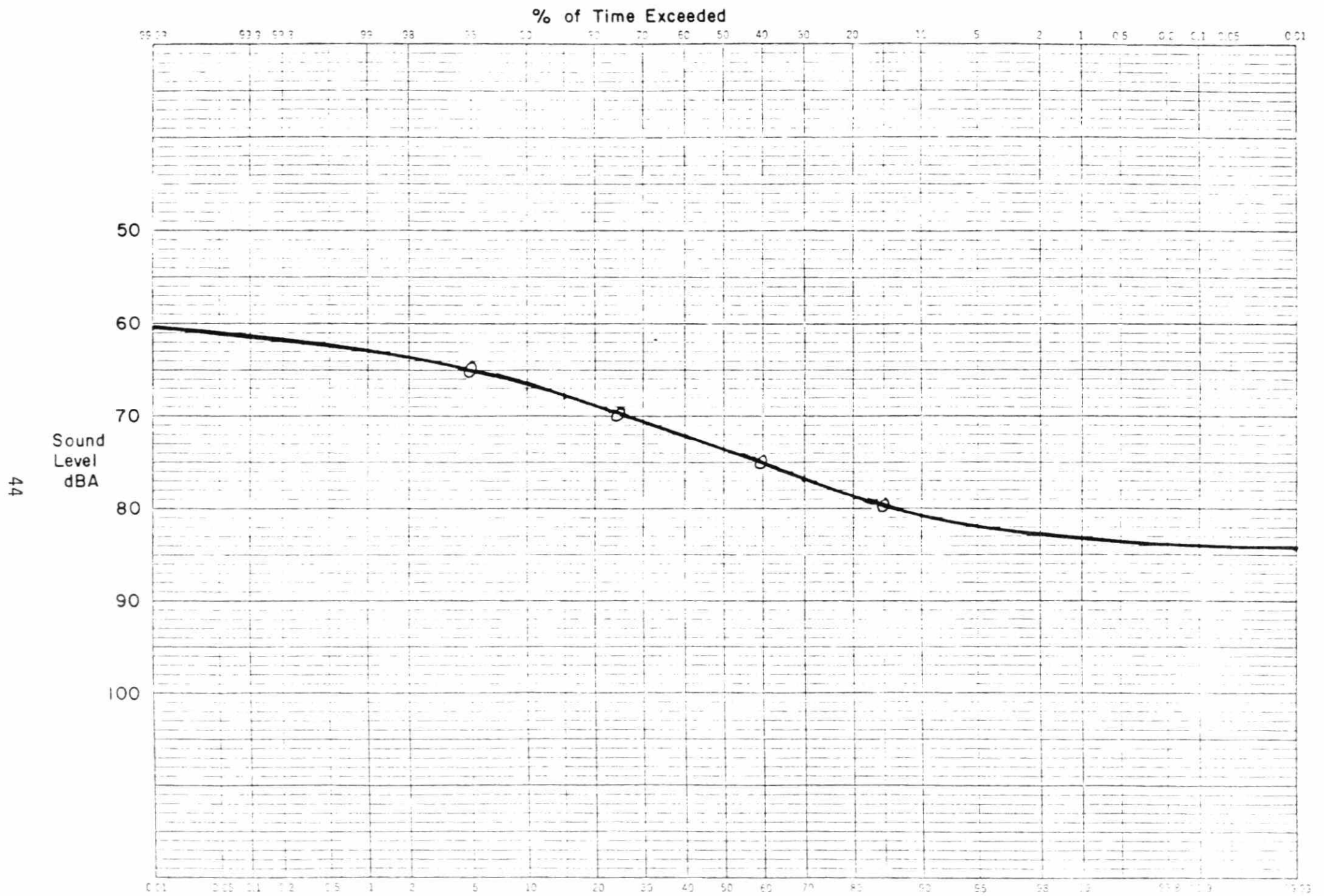


Figure V.1.C.4.: Cumulative Distribution Plotted on Statistical Distribution Paper

V.1.C.5. THE CONCEPT OF THE EQUIVALENT ENERGY CONTINUOUS LEVELS

For many years acousticians have searched for a method of describing time varying sounds by a single number rather than by the entire cumulative distribution or even certain L_N values picked off such a distribution.

In order to assess time-varying noises, the unsteady sound level (still measured in dBA) could be averaged in some way to provide an equivalent continuous level which would have the same annoyance value as the original sound. Exactly how this averaging is to be performed can only be decided by research into the response of human beings to varying noises. Considerable research has been done to determine how this averaging should be performed.

Simple averaging of the time varying pressure of the sound is not a good method of assessing the annoyance of unsteady, intrusive noises. This method tends to underestimate the annoyance value. It is clear from this statement that an averaging method is required which puts more emphasis on the higher levels than simple pressure averaging. It has been found that if the energy (which is proportional to the square of the pressure) of a time varying sound is averaged, then the resulting energy equivalent continuous level (L_{eq}) has good correlation with the annoyance of that sound.

For the purpose of certain environmental noise controls in Ontario, the community noise descriptor L_{eq} has been selected. The adoption of L_{eq} does not necessarily preclude the use of other descriptors.

% of Time Exceeded

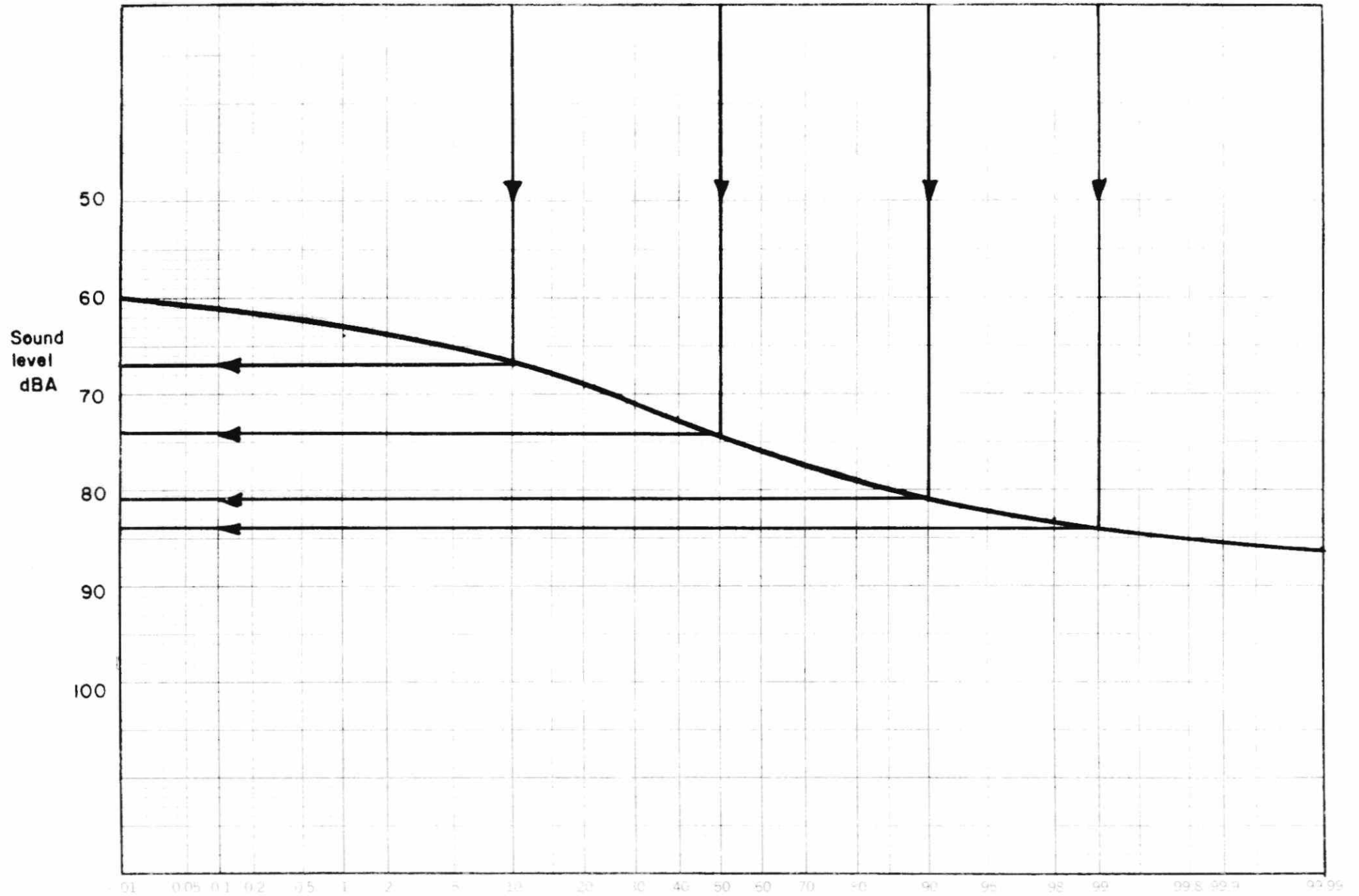


Figure V.1.C.5.: Use of Statistical Distribution Paper

V.1.C.5.1 The Definition of L_{eq} :

The energy equivalent continuous level is that constant sound level which has the same energy as a time-varying noise for a specified time duration. In order to understand fully the concept for L_{eq} it is also necessary to consider the mathematical definition.

$$L_{eq} = 10 \log \frac{1}{T} \int_0^T \left(\frac{P_A(t)}{P_0} \right)^2 dt \quad \text{dBA... (V.1.C.1)}$$

where, P_0 = the standard reference pressure 20 μPa .
 $P_A(t)$ = the A-weighted time varying sound pressure.
 T = to the measurement duration.

Example:

The noise from a certain machine was measured and found to consist of three constant levels for the following times in a one hour period.

78 dBA for 30 minutes

80 dBA for 20 minutes

83 dBA for 10 minutes

(NOTE: that the total time of measurement is 60 minutes.)

Calculate the L_{eq} value.

First the sound level relationship must be applied to find the pressure squared ratio for each time period.

$$L_A = 10 \log \left(\frac{P_A}{P_0} \right)^2$$

$$\left(\frac{P_A}{P_0} \right)^2 = \text{antilog} \left(\frac{L_A}{10} \right)$$

Thus to determine the pressure squared ratio, each sound level must be divided by ten and antilogged as follows:

78 divided by 10 gives 7.8, antilogged gives 6.3×10^7 for 30 min.

81 divided by 10 gives 8.1, antilogged gives 1.26×10^8 for 20 min.

83 divided by 10 gives 8.3, antilogged gives 2.0×10^8 for 10 min.

Now the formula for L_{eq} can be used to integrate these levels over a 60 minute period.

$$\begin{aligned}
L_{eq} &= 10 \log \left[\frac{1}{60} (6.3 \times 10^7 \times 30 + 1.25 \times 10^8 \times 20 + 2.0 \times 10^8 \times 10) \right] \\
&= 10 \log \left[\frac{1}{60} (189 \times 10^7 + 25 \times 10^8 + 20 \times 10^8) \right] \\
&= 10 \log \left[\frac{1}{60} (63.9 \times 10^8) \right] \\
&= 10 \log [1.06 \times 10^8] \\
&= 10 \times 8.03 \\
&= 80.3 \\
L_{eq} &= 80 \text{ dBA for one hour. } \longrightarrow
\end{aligned}$$

The table for logarithms and antilogarithms are provided in Tables V.1.C.2 and V.1.C.3.

It is interesting to consider the L_{eq} derivation for constant sound level. In this case the averaging process (integration over time T and division by time T) is unnecessary as the average of a constant is that constant. Thus for a constant sound level the equation reduces to exactly the same equation as the definition of dBA, that is for a steady sound:

$$L_{eq} = L_A = 10 \log \left(\frac{P_A}{P_0} \right)^2 \quad \text{dBA... (V.1.C.2)}$$

Thus for a steady sound the L_{eq} value will be the same as the dBA value. This is to be expected as a sound level meter gives a good assessment of steady sounds by measuring a dBA level, and any assessment of unsteady sounds should not be in conflict with this.

It has already been stated that an L_{eq} measurement is always performed for a certain measurement duration and is not an instantaneous reading as with a sound level meter. For this reason it is usual to state the time duration of the measurement along with the L_{eq} value. If a short time sample of the noise is taken then the value of L_{eq} will apply for the time the noise source is on. The fact that an L_{eq} measurement applies for a certain time means that two noise sources which are on for different times cannot be directly compared by their L_{eq} values. One of the L_{eq} values must first be corrected to the same time duration as the other source to allow direct comparison of levels. To be able to do this a trade-off relationship between level and time is required.

V.1.C.6 TRADE-OFF RELATIONSHIP OF TIME vs SOUND LEVEL

The trade off relationship can easily be derived from the mathematical definition of L_{eq} already given. Let a noise source produce a certain L_{eq1} with a corresponding equivalent pressure P_{eq1} for a time T_1 . Consider the effect of taking an L_{eq} measurement over a longer time T_2 . Let the value of L_{eq} obtained from this longer test be L_{eq2} then:

$$L_{eq2} = 10 \log \frac{1}{T_2} \int_0^{T_1} \left(\frac{P_{eq1}}{P_o} \right)^2 dT \quad \text{dBA... (V.1.C.3)}$$

The pressure P_{eq1} need only be integrated over time T_1 as it is off for the rest of the time.

$$\begin{aligned} L_{eq2} &= 10 \log \frac{T_1}{T_2} \left(\frac{P_{eq1}}{P_o} \right)^2 \\ &= 10 \log \frac{T_1}{T_2} + 10 \log \left(\frac{P_{eq1}}{P_o} \right)^2 \\ &= 10 \log \frac{T_1}{T_2} + L_{eq1} = -10 \log \frac{T_2}{T_1} + L_{eq1} \end{aligned}$$

or re-arranging, $L_{eq2} = L_{eq1} - 10 \log \frac{T_2}{T_1} \quad \text{dBA... (V.1.C.4)}$

This relation shows that an L_{eq} value for a certain time duration will always be decreased when the time is lengthened. This relationship should always be used with great care. Before it is used it is necessary to understand the correct method of extending an L_{eq} measurement to a longer duration. Two situations exists. First if a short representative sample is taken of a noise source the L_{eq} value obtained will apply for as long as the source is on. For times longer than that for which the machine is on, that is time which necessarily include periods when the machine is off, then the trading relationship must be used. The time that the source is off will reduce the L_{eq} which is exactly what the trade off relationship should do.

V.1.C.6.1 Example of Transforming Measured L_{eq} Values to a Different Time Duration;

This transformation can be illustrated through the following example:

EXAMPLE:

A representative sample of noise was taken for 5 minutes, and the L_{eq} value of 69 dBA calculated. By observation it was found that the source in question was on for a total of six hours between 07:00 and 19:00. Calculate the L_{eq} for the day time period (07:00 to 19:00 hours).

$$L_{eq} \text{ for 5 minutes} = 69 \text{ dBA}$$

$$L_{eq} \text{ for 6 hours} = 69 \text{ dBA}$$

(machine is on for 6 hours)

The L_{eq} for 12 hours (07:00 to 19:00) is required $T_1 = 6$ hours,
 $T_2 = 12$ hours.

$$L_{eq2} = 69 - 10 \times \log \frac{12}{6} \quad (\text{refer to equation (V.1.C.4)})$$

$$= 69 - 10 \times \log 2$$

$$= 69 - 10 \times 0.3$$

$$= 69 - 3$$

$$L_{eq} = 66 \text{ dBA for 12 hours.} \longrightarrow$$

- Notice that if the duration is doubled then 3 dB is subtracted from the old L_{eq} to give the new L_{eq} value.
- Also note that L_{eq} values for 5 minutes and 6 hours are the same since the 5 minute sample was a representative sample of the noise.

V.1.C.7 CALCULATION OF L_{eq} FROM L_{50} AND L_{10} (for Gaussian Noise):

It is often required to calculate L_{eq} (the energy equivalent continuous sound level) from L_{50} and L_{10} which can easily be obtained from a cumulative distribution curve.

This can be done, but only for a Gaussian distribution, with a cumulative distribution that becomes a straight line when plotted out on statistical distribution paper. The formula is as follows:

$$L_{eq} = L_{50} + 0.07 (L_{10} - L_{50})^2 \quad \dots(\text{V.1.C.5})$$

for Gaussian distribution only.

From the cumulative distribution in Figure V.1.C.5.

$$L_{50} = 74 \text{ dBA}$$

$$L_{10} = 81 \text{ dBA}$$

$$L_{eq} = 74 + 0.07 (81 - 74)^2$$

$$= 77.4$$

$$L_{eq} = 77 \text{ dBA} \longrightarrow$$

As a check L_{eq} was obtained directly from the statistical distribution by the method covered in this lecture and found to be 77 dBA. Thus for Gaussian noises, L_{eq} can be simply and accurately found from L_{50} and L_{10} . The formula should NOT be used for non-Gaussian distribution, that is, those which are not closely straight lines when plotted on statistical distribution paper.

V.1.C.7.1 The Usefulness of L_{eq} Versus L_{90} , L_{50} , L_{10} and L_1 as Community Noise Descriptors:

In the topic V.1.C.10, the L_{eq} was described as being a single number descriptor of time-varying or non-steady noise. Although it has been found to be a good rating scale for the assessment of annoyance due to time-varying noise, it may not apply in some cases. Thus it may be necessary when rating a community noise for annoyance to be more flexible and consider instead the cumulative distribution in general and several L_N levels (such as L_{90} , L_{50} , L_{10} and L_1) in particular. In this manner the measurement can be assessed. It may be thought that taking four L_N parameters may be a heavy-handed approach, but to be more certain of correctly rating the annoyance due to widely differing types of sound variations, such an approach may well be safer.

A second difference between L_{eq} and the cumulative distribution parameters is that L_{eq} emphasises the higher levels and produces dBA values higher than simply averaging would produce (because it is an energy average and not a simple pressure average). Thus L_{eq} tends to be more representative of the higher noise levels, and is thus a good measure of high level intrusive type noises. However, it often happens that despite the presence of high level intrusions, a moderately high, almost continuous, background level will be the more annoying. In this case L_{eq} would not rate the total noise situation accurately and L_{90} or L_{50} would be a better descriptor.

A further property of L_{eq} is that it responds to changes in the duration of levels of sound levels much more steadily and continuously as compared to the L_N numbers. This is illustrated below:



EXAMPLE:

Consider a noise climate in which continuous levels of 40 and 80 dBA prevail for the following different times:

- (a) 85% and 15% time, respectively,
- (b) 88% and 12% respectively,
- (c) 91% and 9% respectively,
- (d) 100% and 0 respectively,

The L_{eq} and L_{10} values are computed for all the above cases over the entire interval as listed below:

- (a) $L_{10} = 80$ dBA, $L_{eq} = 72$ dBA
- (b) $L_{10} = 80$ dBA, $L_{eq} = 71$ dBA
- (c) $L_{10} = 40$ dBA, $L_{eq} = 70$ dBA
- (d) $L_{10} = 40$ dBA, $L_{eq} = 40$ dBA

The change in the values of L_{eq} is noted to be relatively gradual from case (a) to (d) whereas L_{10} changed in a step from 80 to 40 dBA as the noise climate changes. The ability of L_{eq} to reflect such changes is an important one and is worthy of consideration when assessing the noise climate in a community.

V.1.C.7.2 The Importance of Measurement Duration in Community Noise Measurements:

It is very important when taking community noise measurements, to obtain a representative sample. Consider the situation of an industry producing fairly continuous mid-level noise and occasionally performing a venting operation which produces a higher level for a short period of time. In this situation, it would be incorrect to analyse the continuous level on its own without the higher level noise. It would also be incorrect to analyse the high level and ignore the period when the lower continuous level was present. Clearly, in this case, a time period must be analysed which contains both noise situations, and further, does not place unequal weight on either situation. To ensure that a representative sample has, in fact, been taken, a considerable time period may have to be analysed. In some cases up to several hours or the entire day, evening or night period are monitored on the site and the results analysed.

The second generation of acoustical instrumentation makes this procedure relatively simple and accurate. Such instrumentation is mentioned in V.3.A.

SUBJECT:
ACOUSTICS TECHNOLOGY IN
LAND USE PLANNING

TOPIC: V.I.D.
SOUND LEVEL LIMITS

OBJECTIVES:

Trainee will be able to:

1. Discuss the need for sound level limits;
 2. Understand how, when and where the limits set forth in the Model Municipal Noise Control By-law, NPC-131 are used.
-

V.1.D.1. THE NEED FOR SOUND LEVEL LIMITS

Having recognized that high noise levels can have an adverse effect on human beings (through speech, activity and sleep interference) a set of sound level limits are required for two basic reasons: First to decide whether a particular noise environment is excessive or not and, secondly, as an objective for the design of noise control measures when sound levels are found to be excessive.

The stages in setting up sound level limits follow fairly naturally from these two requirements. First, the relevant human activities in the relevant situation (residence, motel, office etc.) must be listed; second, the time and place of such activities should be determined; thirdly, the noise level descriptors (such as L_{eq} , L_1 , L_{10} , etc.) most applicable to the particular activity interference should be determined; and, finally, a number assigned to the descriptor(s) to act as the dividing line between a good and a poor noise environment and also as a target for the reduction of noise. This process could well result in a list of sound level limits which can be simplified by taking the most sensitive activity and, hence, the lowest limit for a particular time and place and ignoring the other activities.

A partial table of human activity on residential property follows:

Activity	Time	Place
Gardening	day and evening	outdoors
Relaxing	day and evening	outdoors and indoors, living room
Studying	weekends, evening weekdays	indoors, Living room
Cooking	prior to any mealtime, day and evening	indoors, kitchen
Sleeping	night	indoors, bedroom
Conversation (including telephone)	day and evening	indoors and outdoors

Table V.1.D.1. Summary to Activities on Residential Property

In addition to these activities certain other factors need consideration. Annoyance is one example of this. Even though a person is doing nothing in particular, a noise could well be annoying, irritating or even unbearable, even though it did not disturb any particular activity. Hearing loss may also be a consideration. There is some support for the theory that even common everyday sound such as vacuum cleaners, radios or local traffic can contribute to hearing loss. What was thought to be age-induced hearing loss could well be a loss due to continuous exposure to even moderate sound levels.

The choice of which noise descriptors are to be used to rate particular noises is an area of continuing discussion in the acoustical community. Many such descriptors exist and the choice of which is the best for all noise sources is not settled. Sociological surveys, jury testing and other research methods have, however, provided valuable information on the relative merits of certain noise descriptors, making possible the selection of a few descriptors to cover most situations. One significant exception to this is aircraft noise, where an individual descriptor and rating system has been set up. Sound level limits for aircraft are covered in Topic V.5.A.

The leading descriptor used by the Noise Pollution Control Section in its sound level limits is the equivalent energy continuous level (L_{eq}). A second descriptor (L_{50}) is also used, but need only be considered in cases of near - continuous industrial or highway noise.

The complete set of sound level limits recommended by the Noise Pollution Control Section are presented in Noise Publication NPC-131, attached to the Model Municipal Noise Control By-law as published by the Ministry of the Environment. NPC-131, "Guidelines for Noise Control in Land Use Planning" is reprinted in full in the following section.

Publication NPC-131

Guidelines for Noise Control in Land Use Planning

1. Scope

This Publication refers to the noise environment on the site of proposed residential or other sound-sensitive development in an urban area. Specified sound-level limits should apply to a new development as well as alteration to, or conversion of, any existing development or construction. Rural and special residential land use may be subject to different conditions. For sound-level limits on the site of a proposed residential or other sound-sensitive development influenced by aircraft noise, reference should be made to Publication NPC-126 - Guidelines on Aircraft Noise.

2. Definitions

(1) Technical Definitions

The technical terms used in this Publication are defined in Publication NPC-101 - Technical Definitions.

(2) Definitions Specific to this Publication

(a) Outdoor Recreational Areas

"Outdoor recreational areas" refers to those outdoor areas where the enjoyment of the outdoor environment is important. These areas include, but are not limited to, the following:

- (i) yards including front yards, backyards, gardens, terraces or patios of dwellings;
- (ii) common outdoor areas allocated for recreational purposes such as areas outside apartment buildings, condominiums, group homes, hospitals and schools;
- (iii) parks and open spaces allocated for recreational purposes within a plan of subdivision.

(b) Control Measures

"Control measures" refers to actions which can be taken to achieve noise compatibility for the specific land use or activity. Control measures may include, but are not limited to, the following:

- (i) Site Planning - orientation of buildings and outdoor recreational areas with respect to noise sources, spatial separation such as insertion of sound-insensitive land uses between source and receiver and appropriate setbacks;
- (ii) Acoustical Barriers - berms, walls, favourable topographical features; other intervening structures;
- (iii) Architectural Design - room and corridor arrangement; blank walls, placement of windows, balconies and courtyards, building height;
- (iv) Construction - acoustical treatment of walls, ceilings, windows and doors, selection of acoustical materials and other control devices.

3. Indoor Sound Level Limits

- (1) Table 131-1 as adjusted in accordance with subsection (2), if necessary, gives the equivalent sound level (L_{eq}) limits and the applicable time periods for the indicated types of indoor space. These are the minimum requirements of these Guidelines and apply in all cases.
- (2) When the predominant sound has pronounced tonal quality such as a whine, screech, buzz, or hum or contains pronounced narrow bands of energy, then 5 dBA should be deducted from the sound level limits indicated in Table 131-1.

4. Outdoor Sound Level Limits

- (1) Table 131-2 gives the sound level limits for two descriptors, the 50th percentile sound level (L_{50}) and the equivalent sound level (L_{eq}) for outdoor recreational areas, where the descriptors are referenced to the entire 16 hour period from 07:00 to 23:00 hours. The 50th percentile need only be considered for developments where the predominant sound is industry or a highway producing near constant sound levels.

Compliance with these sound level limits should generally ensure compliance with the appropriate requirements of Table 131-1 for the same time period for any normal building construction nearby.

- (2) Table 131-3 gives the sound level limits for two descriptors, the 50th percentile sound level (L_{50}) and the equivalent sound level (L_{eq}), for outdoor areas, in the vicinity of buildings or proposed buildings containing sleeping quarters, where the descriptors are referenced to the entire 8 hour period from 23:00 to 07:00 hours. The 50th percentile need only be considered for developments where the predominant sound is industry or a highway producing near constant sound levels.

Compliance with these sound level limits should generally ensure compliance with the appropriate requirements of Table 131-1 for the same time period for any normal building construction nearby.

- (3) Where the requirements of Table 131-3 cannot be met, special architectural design or construction features will have to be incorporated into the building construction to ensure compliance with the appropriate requirements of Table 131-1 for the same time period.

5. Planning the Project

(1) Responsibility of Developer

The developer or proponent of a new project, or project to convert an existing use, for a residential or sound-sensitive development in an urban area, should be responsible for investigating both the outdoor and potential indoor acoustical environments, and to determine the feasibility and the constraints applicable before any project action is taken or construction commitment made.

(2) Establishing the Sound Levels On-Site

The sound levels anticipated on the site should be established by the use of prediction techniques acceptable to the Minister, based when necessary on actual measurements. In all cases, consideration should be given to anticipated future increases in sound levels for at least ten years.

(3) Control Measures

When anticipated sound levels on the site of the land use development under consideration, exceed the recommended sound level limits, the land developer should institute appropriate control measures or revision to plans.

(4) Ventilation

When special architectural design or construction features are used as control measures and thereby restrict indoor ventilation, then air conditioning or forced air ventilation systems should be provided.

V.1.D.3. APPLYING RECOMMENDED SOUND LEVEL LIMITS TO RESIDENTIAL
LAND USE DEVELOPMENTS

Table V.1.D.2. allows one to determine the subjective or apparent loudness of the traffic noise on the site, the extent of the noise problem and the necessity of investigating noise control measures. The Table should be used in conjunction with the Sound Level Limits discussed in V.1.D.2.

Table 131-1
Indoor Sound Level Limits

Type of Space	Equivalent Sound Level (L_{eq}), dBA ^{eq}
Bedrooms, sleeping quarters, hospitals, etc. (Time period 23:00-07:00 hours)	40
Living rooms, hotels, motels, etc. (Time period 07:00-23:00 hours)	45
Individual or semi-private offices, small conference rooms, reading rooms, classrooms, etc. (Time period 07:00-23:00 hours)	45
General offices, reception areas, retail shops and stores, etc. (Time period 07:00-23:00 hours)	50

Table 131-2
Sound Level Limits for Outdoor
Recreational Areas (07:00-23:00 hours)

Sound Descriptor for the Entire Period	Sound Level Limit, dBA
L_{50}	52
L_{eq}	55

Table 131-3
Sound Level Limits for Outdoor
Areas (23:00-07:00 hours)

Sound Descriptor for the Entire Period	Sound Level Limit, dBA
L_{50}	47
L_{eq}	50

Table V.1.D.2. Applying Recommended Sound Level Limits to Residential Land Use Developments

Excess Above Recommended Sound Level Limits dBA	Change in Subjective Loudness Above	Magnitude of the Noise Problem	Noise Control Measures (or action to be taken)
No excess	--	No expected noise problem	None
1 to 5 inclusive	Noticeably louder	Slight noise problem	Optional (if no physical measures are taken then prospective purchasers or tenants should be made aware by a clause in the deed or rental agreement)
6 to 10 inclusive	Almost twice as loud	Definite noise problem	Recommended
11 to 15 inclusive	Almost three times louder	Serious noise problem	Strongly recommended
16 and over	Almost four times louder	Very serious noise problem	Strongly recommended (may be mandatory)

SUBJECT:
ACOUSTICS TECHNOLOGY
IN LAND USE PLANNING

TOPIC: V.2.A.
NOISE PREDICTION METHODS

OBJECTIVES:

The trainee will be able to:

1. List the reasons for using transportation noise prediction methods;
 2. Describe and use the Ontario Highway Noise Prediction Method to determine the noise levels due to traffic on a highway;
 3. Describe and use the Train Noise Prediction Method to determine the noise levels due to train pass-bys.
-

V.2.A. NOISE PREDICTION

In the field of acoustics and land use planning, prediction methods are used primarily to determine the noise impact from various transportation noise sources such as roads, railways and aircraft operations.

There are a number of reasons for the extensive use of prediction methods in noise impact assessment. First, it allows persons who do not have measurement capabilities to obtain an indication of the noise levels on a particular site. Second, it allows the noise levels on a site to be determined when the constraints of time, money, distance, weather and instrumentation do not permit on-site measurements. The use of prediction methods also allow the evaluation of changes in the transportation facility noise source. For example, the effect of a future increase in the volume of traffic on a particular road can easily be calculated. The prediction methods also allow the effectiveness of some noise control measures to be evaluated particularly the effect of increasing the distance between the noise source and the receiver.

There are a number of transportation noise prediction methods that have been developed for the three sources of transportation noise - traffic, railways and aircraft.

This section will describe (in detail) the two prediction methods used extensively by the Noise Pollution Control Section to determine the noise impact from road traffic and train operations on land being developed for residential use.

The noise prediction methods used extensively in the Road Traffic Noise Tables will also be discussed. That manual is an integral part of the training course.

V.2.A.1. ROAD TRAFFIC NOISE PREDICTION

V.2.A.1.1. Ontario Highway Noise Prediction Method (RR 197)

The Ontario Highway Noise Prediction Method is an empirical noise prediction method developed by the Ontario Ministry of Transportation and Communications. It is based on 133 sound level measurements taken at 120 locations near rural and urban freeways, highways and along residential streets in Ontario.

The procedure for using the Ontario method involves the use of the basic relationships established between traffic flow volumes, traffic speed, distance and sound levels.

The following relationships form the basis of the Ontario Highway Noise Prediction Method:-

$$L_{50} = 30.4 + 14.5 \log_{10} (V_c + 3V_t) - 11.5 \log_{10} D + 0.16S \quad \dots(V.2.A.1.)$$

$$L_{10} = 52.7 + 11.2 \log_{10} (V_c + 3V_t) - 14.8 \log_{10} D + 0.21S \quad \dots(V.2.A.3.)$$

$$L_5 = 56.5 + 11.1 \log_{10} (V_c + 3V_t) - 16 \log_{10} D + 0.23S \quad \dots(V.2.A.3.)$$

where:

L_{50}, L_{10}, L_5 = sound levels in dBA which were exceeded 50, 10, or 5 percent of the time (refer to V.1.C. for a discussion on noise descriptors, including L_{eq})

V_c = hourly volume of cars (GVW $\leq$ 10,000 lb)

V_t = hourly volume of trucks (GVW $>$ 10,000 lb)

D = distance (in feet) from the edge of the pavement to the observer location.

S = average operating speed of traffic flow in miles per hour.

Recently, an L_{eq} Traffic Noise Prediction Method has been developed which is also an empirical method based on a number of sound level measurements taken in Ontario. The relationship between traffic flow volumes, traffic speed, distance and sound level was found to be as follows:

$$L_{eq} = 49.5 + 10.2 \log_{10} (V_c + 6V_t) - 13.9 \log_{10} D + 0.21S \quad \dots (V.2.A.4)$$

where:

- L_{eq} = energy equivalent sound level during an hour, in dBA.
- V_c = hourly volume of cars ($GVW \leq 10,000$ lb)
- V_t = hourly volume of trucks ($GVW > 10,000$ lb)
- D = distance (in feet) from the edge of pavement to the observer location.

The Model Municipal Noise Control By-law, Publication NPC 131, Guidelines for Noise Control in Land Use Planning was revised in May, 1976 to recommend design sound level limits for new residential developments in terms of two noise descriptors - L_{50} and L_{eq} . The $L_{eq} = 55$ dBA sound level limit, referenced to the entire 16 hour daytime period (07:00 to 23:00 hours) is applicable in all cases while the $L_{50} = 52$ dBA sound level limit, referenced to the same daytime period, need only be considered for developments where the predominant sound is a roadway producing near constant sound levels or from industry. (See also V.1.D. for a discussion on sound level limits). Therefore, for the purposes of this course we will restrict our use of the highway noise prediction methods to determining the L_{50} and the L_{eq} sound levels.

V.2.A.1.2. Road Traffic Variables

The following variables are included in the Ontario Highway Noise Prediction Method:

- (i) Volume of cars and trucks (in vehicles per hour).
- (ii) Traffic flow speed (in m.p.h.).
- (iii) Distance from the edge of the nearest lane of pavement to the receiver (in feet),
- (iv) Highway gradient (in percent),
- (v) Pavement surface texture.

V.2.A.1.3. Procedure - To Determine the Value of the Variables

- (i) Determine the traffic volume for the facility in question ten years hence.

If the peak hour traffic volume or the design hour traffic volume is available it may be used. If only the daily (24 hour) Traffic Volume is available, the largest of the Annual Average Daily Traffic (AADT), Summer Average Weekday Daily Traffic (SAWDT), the Winter Average Daily Traffic (WADT) should be used.

If only the present (existing) Traffic Volume is available, then this volume should be multiplied by 1.6 to give the volume assumed for ten years hence. This factor of 1.6 is based on the assumption of a 5% increase per year in the traffic volume for ten years and can be expressed mathematically as $(1.05)^{10}$.

The daily (24 hour) traffic volume should then be divided by 24 to give an approximate hourly traffic volume.

- (ii) Determine the truck volume of the total volume from (i) above. Trucks are defined as being all vehicles with a Gross Vehicle Weight (GVW) greater than 10,000 lbs. The truck volume will usually be given as a percentage of the total traffic volume. If no truck percentage is known, assume it to be 15%. Use this truck percentage to obtain the number of cars and trucks in the peak hour, design hour or calculated hourly traffic volume.

EXAMPLE

Given:

Hourly traffic volume (total) 10 years hence	667 V.P.H
truck percentage	15%
hourly truck volume = $667 \times .15$	100 trucks
hourly car volume = $667 - 100$	567 cars

- (iii) Determine the traffic flow speed or the operating speed, if known. If this information is not available use the posted speed limit for the roadway in question.

(iv) Determine the distance (in feet) from the nearest roadway edge of pavement (E.O.P.) to the observer location. The observer location is usually considered to be the approximate position of the nearest wall of the row of normal housing nearest to the roadway.

(v) Determine the highway gradient. The highway gradient refers to the slope of the road determined by dividing the difference in vertical elevation between two points on the roadway by the roadway distance between these two points and multiplying the result by 100 to express the grade as a percentage.

Figure V.2.A.1. indicates how the Highway Gradient should be calculated. The calculation would be as follows:

$$\text{Road Gradient in \%} = \frac{\Delta h}{3w} \times 100$$

where

Δh = difference in elevation between points A & B

w = subdivision width measured parallel to the roadway.

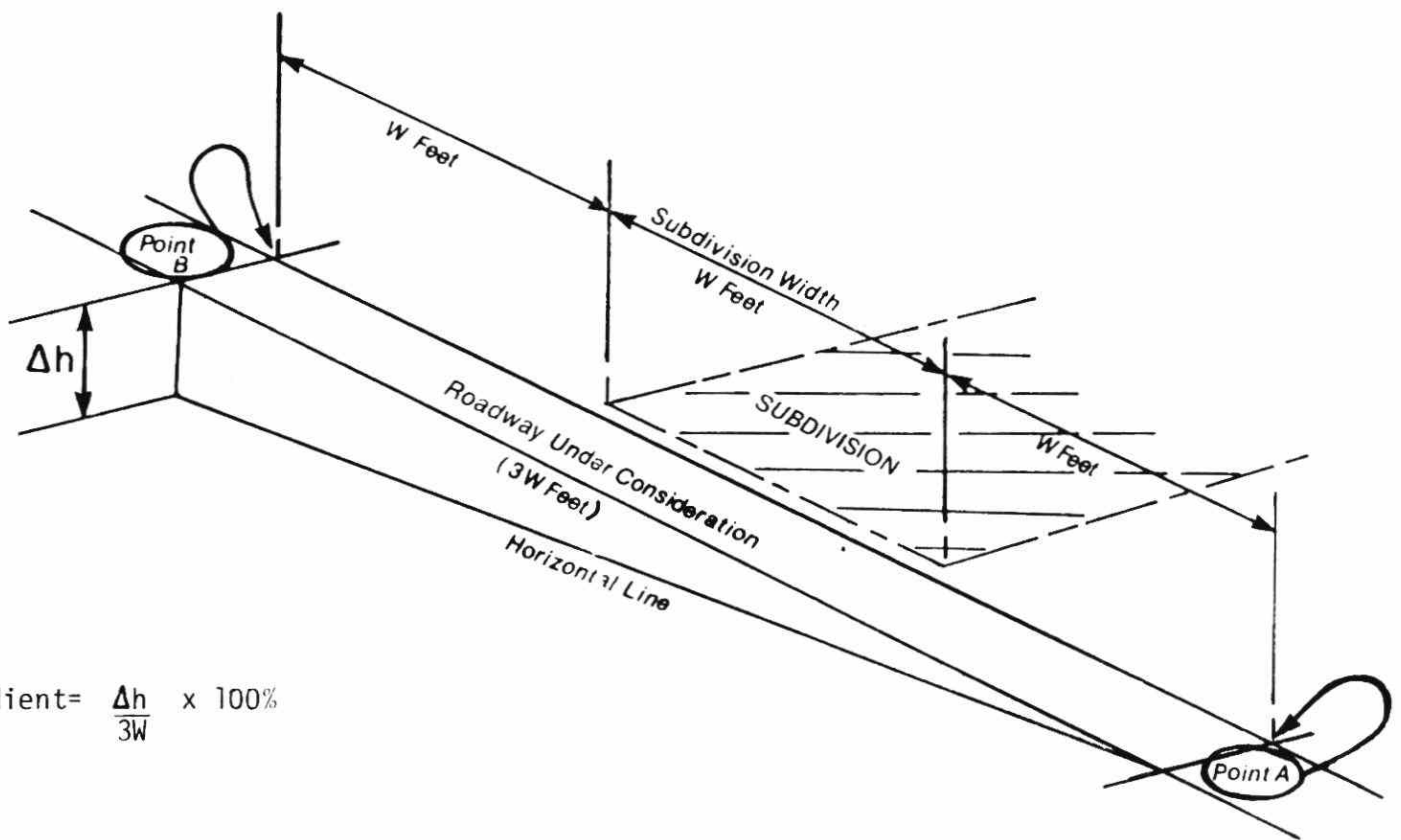
3w = length of roadway between points A & B.

If Road Gradient information is not available, assume it to be 0%.

The following Table gives coefficients which may be used to multiply truck volumes to account for the increase in truck noise on grades. The adjustment for highway gradient is made only for trucks on grades steeper than about 2%.

Gradient %	Coefficient for Truck Volume Multiplication
≤ 2	1
3 - 4	1.5
5 - 6	2
≥ 7	3

The above coefficients are used in addition to the multiplication coefficients (3 for L_{50} and L_{10} , and 6 for L_{eq}) built into the models.



Gradient = $\frac{\Delta h}{3W} \times 100\%$

Figure V.2.A.1.: Definition of Road Gradient

EXAMPLE

If the hourly truck volume (both directions) on a 6 percent grade is 150 trucks, the number of trucks is multiplied by a coefficient of 2 (from the above table) and the resulting truck volume of 300 (150 X 2) is used for the calculation of the sound levels.

- (vi) Determine the adjustment for the pavement surface type based on the following Table.

Surface Type	Description	Adjustment (dB)
smooth	Very smooth, seal-coated, asphalt pavement	-5
normal	moderately rough asphalt and concrete surface	0
rough	rough asphalt pavement with large voids $\frac{1}{2}$ in. (12.7 mm) or larger in diameter, grooved concrete	+5

In most cases, unless specific information is available it is assumed that the subject roadway has a normal surface type and, as a result, no adjustment is required.

V.2.A.1.4. Worked EXAMPLE of an L_{eq} Traffic Noise Prediction

Given:

- | | |
|---|---------------|
| - total hourly traffic volume ten years hence | 2000 vehicles |
| - truck percentage | 15% |
| - posted speed limit | 50 mph |
| - distance from E.O.P. | 100 feet |
| - road gradient | 2% |
| - road surface type | normal |

Procedure:

- hourly traffic volume (total) 2000 vehicles
- 15% trucks therefore hourly truck volume =
 $2000 \times 15\% = 300$ trucks
- hourly car volume = $2000 - 300 = 1700$ cars

Substituting these values into

$$L_{eq} = 49.5 + 10.2 \log_{10} (V_c + 6V_t) - 13.9 \log_{10} D + 0.21S \quad \dots\dots(V.2.A.4.)$$

from information given:

$$V_c = 1700 \text{ cars per hour}$$

$$V_t = 300 \text{ trucks per hour}$$

$$D = 100 \text{ ft.}$$

$$S = 50 \text{ mph}$$

we get

$$\begin{aligned} L_{eq} &= 49.5 + 10.2 \log_{10} (1700 + 6(300)) - 13.9 \log_{10} 100 + 0.21(50) \\ &= 49.5 + 10.2 \log_{10} 3500 - 13.9 \log_{10} 100 + 10.50 \\ &= 49.5 + 36.15 - 27.80 + 10.50 \quad \dots\dots(V.2.A.5.) \\ &= 68.35 \\ &= 68 \text{ dBA (say)} \end{aligned}$$

The noise level at a distance of 100 feet from the roadway with the indicated traffic conditions is 68 dBA.

V.2.A.1.5. The Effect of Changing the Traffic Flow Conditions on the Predicted Noise Levels

(i) Effect of Increasing the traffic volume.

In Equation V.2.A.4., the term $10.2 \log_{10} (V_c + 6V_t)$ indicates the relationship between traffic volume and sound level. The multiplication coefficient of 6 in the traffic volume term suggests that the sound level of an average truck is about 8 dBA higher than the sound level of an average car.

From the worked example above we know that 300 trucks per hour gave the traffic volume term a value of 36.15.

If we double the traffic volume to 600 trucks and 3400 cars per hour, the value of the traffic volume term $10 \log_{10} (V_c + 6V_t)$ increases to 39.22. When this value is substituted into equation V.2.A.5. it looks like this:

$$L_{eq} = 49.5 + \underline{39.22} - 27.80 + 10.50$$

$$L_{eq} = 71.42 = 71 \text{ dBA} \quad \longrightarrow$$

Remember that the reference traffic noise level was 68 dBA.

Therefore, a doubling of the traffic volume (and keeping the other variables constant) results in a 3 dB increase in the noise level. Another way of looking at the effect of this variable is to say that a halving of the traffic volume will result in a 3 dB reduction in the noise level.

This means that the traffic noise model is relatively insensitive to minor changes in the traffic volume.

(ii) Effect of changing the traffic flow speed

According to the traffic noise model, the L_{eq} sound levels change with speed at the rate of 0.21S. This corresponds to a 2.1 dBA change in L_{eq} sound levels for a change in speed of 10 mph, if all of the other variables are held constant. In the worked example the traffic speed term 0.21S had a value of 10.50 i.e. $(0.21(50))$. If we reduce the speed of the traffic from 50 mph to 40 mph the term 0.21S decreases in value from 10.50 to 8.40. When this value is inserted into the model, equation V.2.A.5. now looks like this:

$$L_{eq} = 49.5 + 36.15 - 27.80 + \underline{8.40}$$

$$L_{eq} = 66.3$$

$$L_{eq} = 66 \text{ dBA} \quad \longrightarrow$$

In the example given in V.2.A.1.4., with speed 50 mph, the noise level was 68 dBA. Thus, a decrease of 10 mph in the traffic speed (from 50 mph to 40 mph) results in a 2 dBA reduction in the noise level, if all the other traffic variables are held constant.

This 2 dBA decrease is very slightly lower than the theoretical value of 2.1 dBA per 10 mph decrease in speed because of rounding off to the nearest dBA.

(iii) Effect of increasing the distance from the edge of pavement (EOP) to the observer location.

The term in the L_{eq} model which deals with distance attenuation is $13.9 \log_{10} D$. In the worked example, the value of the distance attenuation term was 27.80 ($13.9 \log_{10} 100$). If we increase the distance from the edge of pavement to 200 feet, this term has the value of 31.98. When this value is inserted into the model, equation V.2.A.5. now looks like this:

$$L_{eq} = 49.5 + 36.15 - 31.98 + 10.50$$

$$L_{eq} = 64.17 = 64.2 = 64 \text{ dBA} \quad \text{—————}$$

Thus, an increase in distance from the EOP from 100 to 200 feet has resulted in a 4 dBA reduction in the noise level.

The term $13.9 \log D$ provides a theoretical distance attenuation of 4.2 dB per doubling of distance. The 4 dBA per doubling of distance we obtained in this example is due to the rounding off of the calculated noise levels to the nearest dBA and to the fact that the theoretical 4.2 value was an average value based on a number of measurements taken at various distances from the edge of pavement.

V.2.A.1.6. Nomograph Method

The Ontario Highway Noise Prediction Method also includes a series of Nomographs by which the variables of traffic volume, traffic speed, and distance from the edge of pavement can be used to determine the sound level under given conditions.

EXAMPLE

using the L_{50} nomograph to determine the sound levels.

information given: $V_c = 2000$ cars per hour

$V_t = 200$ trucks per hour, $3 \times V_t = 600$

$S = 50$ mph

$D = 200$ ft.

total traffic volume: $= V_c + 3V_t = 2000 + 3(200)$

$= 2000 + 600 = 2600$

Method:

1. Draw a straight line from the column "cars per hour plus 3 X trucks per hour ($V_c + 3V_t$)" to 50 mph on the speed graph. In the example this line is labelled 1.

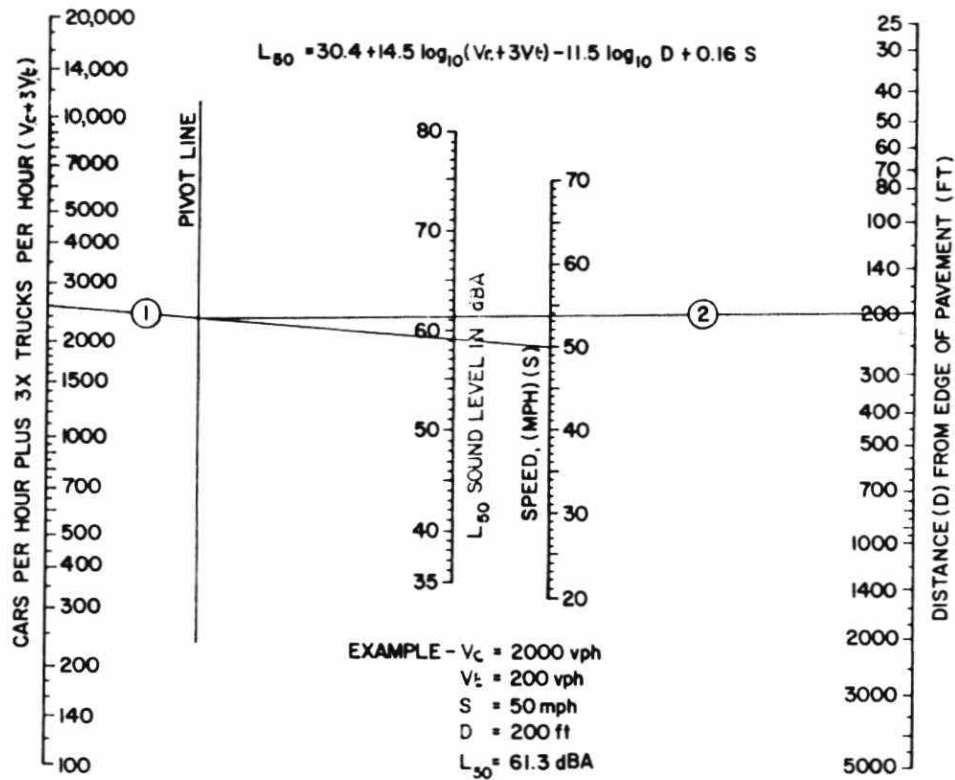


Figure V.2.A.2.: L_{50} Sound Level Prediction

2. Draw a second straight line from the point where line 1 crosses the PIVOT LINE to the 200 foot point on the "distance from edge of pavement" column. In the example this line is labelled 2.
3. Where line 2 intersects with the " L_{50} sound level" column read off the sound level. In this example the L_{50} sound level is 61.3 dBA.
 The L_{50} sound level under the given traffic conditions at a distance of 200 feet from the edge of pavement is 61.3 or 61 dBA.

V.2.A.1.7. Comparison of the Nomograph method and the equation (detailed) method

- using the L_{50} Nomograph and the L_{50} equation
information given:

$V_c = 2000$ cars per hour

$V_t = 200$ trucks per hour $3 \times V_t = 600$

$S = 50$ mph

$D = 200$ feet

$$\begin{aligned} L_{50} &= 30.4 + 14.5 \log_{10} (V_c + 3V_t) - 11.5 \log_{10} D + 0.16S \\ &= 30.4 + 14.5 \log_{10} (2000 + 3(200)) - 11.5 \log_{10} 200 + 0.16(50) \\ &= 30.4 + 49.52 - 26.46 + 8 \\ &= 61.46 = 61 \text{ dBA} \end{aligned}$$

$$L_{50} = 61 \text{ dBA} \quad \longrightarrow$$

The Nomograph method of V.2.A.1.6. gave us an L_{50} value of 61 dBA. Therefore we can say that there is very good agreement between the Nomograph Method and the Detailed (equation) Method.

V.2.A.1.8. Notes on the Use of The Ontario Highway Noise Prediction Method

1. The prediction method assumes that the highway is at grade.
2. The prediction method assumes that there is a direct line of sight between the highway and the receiver.
3. The prediction method should not be used for conditions (speed, traffic volume, and distance) which are outside of the range of values identified by the Nomographs.

V.2.A.1.9. Other Traffic Noise Prediction Methods

(i) Road Traffic Noise Tables

The Traffic Noise Level Prediction portion of the Road Traffic Noise Tables uses the Ontario Highway Noise Prediction Method to determine both the L_{50} and L_{10} levels. The formulae were as follows:

$$L_{50} = 30.4 + 14.5 \log_{10} (V_c + 3V_t) - 11.5 \log_{10} D + 0.16S \quad \dots(V.2.A.1.)$$

$$L_{10} = 52.7 + 11.2 \log_{10} (V_c + 3V_t) - 14.8 \log_{10} D + 0.21S \quad \dots(V.2.A.2.)$$

where: V_c = the number of cars per hour
 V_t = the number of trucks per hour
 D = the distance from the edge of the pavement (EOP) to the receiver (in feet)
 S = the speed (mph)

The equivalent energy continuous sound level (L_{eq}) was then calculated from the two parameters (L_{50} and L_{10}) using the following equation (also given in (V.1.C.)):

$$L_{eq} = L_{50} + 0.070 (L_{10} - L_{50})^2 \quad \dots(V.2.A.6.)$$

It should be noted that this equation applies only for Gaussian (normal) distribution. Since traffic noise is usually closely Gaussian the equation is applicable.

As the theoretical background and the procedure for using the Road Traffic Noise Tables are covered in the document itself, no further reference will be made to the Tables at this time.

Prediction of the L_{eq} of Road Traffic Noise from L_{10} and L_{50}

The L_{eq} will be calculated from the two descriptors L_{50} and L_{10} using the equation:

$$L_{eq} = L_{50} + 0.070 (L_{10} - L_{50})^2 \quad \dots(V.2.A.6.)$$

Given:

- | | |
|---|-----------------|
| - total hourly traffic volume ten years hence | = 2000 vehicles |
| - truck percentage | = 15% |
| - posted speed limit | = 50 mph |
| - distance from edge of pavement | = 100 feet |
| - road gradient | = 0% |
| - road surface type | normal |

Procedure

1. Determine the number of cars and trucks per hour -

$$2000 \times 15\% = 300 \text{ trucks}$$

$$2000 - 300 = 1700 \text{ cars}$$

2. Determine the L_{50} value using:

$$L_{50} = 30.4 + 14.5 \log_{10} (V_c + 3V_t) - 11.5 \log_{10} D + 0.16S \quad \dots\dots\dots(V.2.A.1.)$$

$$= 30.4 + 14.5 \log_{10} (1700 + 3(200)) - 11.5 \log_{10} 100 + 0.16(50)$$

$$= 30.4 + 14.5 \log_{10} 2600 - 11.5 \log_{10} 100 + 8.0$$

$$= 30.4 + 49.4 - 23 + 8$$

$$= 64.8$$

$$L_{50} = 65 \text{ dBA} \longrightarrow$$

3. Determine the L_{10} value using:

$$L_{10} = 52.7 + 11.2 \log_{10} (V_c + 3V_t) - 14.8 \log_{10} D + 0.21S \quad \dots\dots(V.2.A.2.)$$

$$= 52.7 + 11.2 \log_{10} (1700 + 3(300)) - 14.8 \log_{10} 100 + 0.21(50)$$

$$= 52.7 + 11.2 \log_{10} 2600 - 14.8 \log_{10} 100 + 10.5$$

$$= 52.7 + 38.3 - 29.6 + 10.5$$

$$= 71.9$$

$$L_{10} = 72 \text{ dBA} \longrightarrow$$

4. Calculate the L_{eq} sound level using the equation:

$$L_{eq} = L_{50} + 0.070(L_{10} - L_{50})^2 \quad \dots(V.2.A.6.)$$

$$= 64.8 + 0.070 (71.9 - 64.8)^2$$

$$= 64.8 + 0.070 (7.1)^2$$

$$= 64.8 + 3.5$$

$$= 68.3$$

$$L_{eq} = 68 \text{ dBA} \longrightarrow$$

Therefore, the L_{eq} sound level under the given traffic conditions is $L_{eq} = 68 \text{ dBA}$ (an identical result to that obtained in the worked example of V.2.A.1.4.). It must be noted that this equation $L_{eq} = L_{50} + 0.070 (L_{10} - L_{50})^2$ applies only for a Gaussian or normal distribution. Since traffic noise is usually closely Gaussian the equation is applicable.

- (ii) "Highway Noise, A Design Guide for Highway Engineers" - NCHRP Report 117, Transportation Research Board, Washington DC, 1971

This American highway noise prediction method is based upon the principle of adjustment. The 50th percentile level (L_{50}) is established for a reference distance 100 feet from the rear land of an infinitely long, straight, flat roadway. Adjustments are then made to this reference level to account for other distances, roadway geometry, road surface characteristics, and shielding. Since the end result is to be in terms of the 10th percentile level (L_{10} level) an appropriate adjustment is also made to the computed 50th percentile (L_{50} level).

- (iii) Calculation of Road Traffic Noise - Department of the Environment London, HMSO, 1975

This is the "official" British method for calculating noise from road traffic. The document details the procedure necessary to enable entitlement for insulation of residences under the Noise Insulation Regulations, 1975. It is also intended to provide guidance in the design of highways and in environmental planning. While calculation is preferred, measurement methods are also specified.

The noise descriptor used is the L_{10} (18 hour) index (i.e. 06:00 to 24:00 hours) and the method enables L_{10} to be predicted for a wide variety of traffic conditions including traffic flow rate, traffic speed, percentage of heavy vehicles, road surface and gradient. Also taken into account are propagation effects due to barrier screening, partial screening by housing, reflection from surfaces, intervening ground cover and complex road configurations.

One of the major contributors to the prediction method provides schemes for predicting values of other noise descriptors, i.e. L_{50} and L_{90} (Prediction of Traffic Noise Levels, M.E. Delany, NPL Acoustics Report AC 56, 1972).

- (iv) New Housing and Road and Rail Noise (Draft 2) - Central Mortgage and Housing Corporation

The Road Noise portion of this document contains a number of Tables which give the 24 hour equivalent energy continuous sound level (L_{eq}^{24}) for various traffic volumes, truck percentages and speeds at a reference distance of 100 feet from the roadway. Corrections (if necessary) are made to these basic noise levels obtained from the Tables for different road gradients and interrupted traffic flow conditions.

The noise levels in the Tables are based on the pass-by L_{eq} of a single car (and a single truck) as it varies with speed at a distance of 100 feet.

- (v) Urban Traffic Noise Prediction - Ontario Ministry of the Environment, Prepared by J.S. Bradley

This prediction scheme was developed as part of a project supported by an Ontario Government "Experience '76" grant by J.S. Bradley of The University of Western Ontario, Faculty of Engineering Sciences, reported in 1977. A number of L_{eq} prediction tables were developed using a new analytical equation. Predictions are given for various speeds, vehicle flow rates and percentages of heavy trucks.

- (vi) Model Municipal Noise Control By-law - Publication NPC-129 Ontario Ministry of the Environment

This publication describes a method for use in communities of over 10,000 people for the estimation of the L_{eq} due to traffic on roads where speeds are restricted to below 65 km/h, and traffic volumes are below 1500 vehicles per hour i.e. most local roads.

V.2.A.2. TRAIN NOISE PREDICTION METHOD

V.2.A.2.1. Introduction

To provide a basis for efficient land use planning close to railway tracks, a semi-empirical train pass-by noise profile model was developed by the Noise Pollution Control Section. The model is able to predict locomotive levels, wheel rail levels, level rise and fall as the train approaches and recedes, and level decrease with distance.

The original model has been simplified to allow the equivalent energy continuous sound level (L_{eq}) to be predicted for train pass-bys. The model allows the prediction of the noise climate for daytime, night time or 24-hour time periods on lands being considered for development, where train operations may cause some noise impact.

V.2.A.2.2. Information Required

The following information, which is required in order to use the train noise prediction method, can usually be obtained from the local stationmaster, trainmaster or dispatcher of the railroad owning the tracks. In addition to obtaining information on the present or existing train operations it is important to find out if any future increases (or decreases) in the number of trains using the line can be expected. This information is particularly important in areas where a commuter rail service such as GO Transit may be a future possibility. These commuter operations can increase the number of trains on a rail line by a significant amount.

The information required is as follows:

1. The number of train movements per day on the railway line in question. If possible, this information should be broken down into:
 - (a) Time of day;
 - (i) the number and type of trains during the daytime period (07:00 to 23:00 hours)
 - (ii) the number and type of trains during the night time period (23:00 to 07:00 hours).
 - (b) Type;

The type of train refers to whether the train is a passenger, a freight or switcher.

2. The average number of locomotives (if available) and the average number of cars for each type of train.
3. The average speed (in mph) of each type of train.
4. The presence of any special operating conditions at, or near, the subject site, such as trains accelerating, decelerating or 'coasting'.
5. The distance (in feet) from the track centreline to the observer location. This distance is obtained from the site plan, etc.

V.2.A.2.3. Procedure

Information required:

Speed of each type of train, $V(\text{mph})$

Number of trains, N , in the time period $H(\text{hours})$ of interest

Number of locomotives per train, e , (if available)

Number of cars per train, n

Distance from the track centreline, d (in feet).

1. If the number of locomotives per train is not known, obtain from the Table below:

<u>Number of Cars(n)</u>	<u>Assumed Number of Locomotives (e)</u>
$0 < n < 35$	$e = 1$
$35 < n < 70$	$e = 2$
$70 < n < 105$	$e = 3$
$105 < n$	$e = 4$

2. Calculate ' $\frac{n}{e}$ ' - the number of cars per locomotive per train.

NOTE: if the different types of trains are all operating at the same speed the TOTAL NUMBER of LOCOMOTIVES and the TOTAL NUMBER of CARS may be used for this calculation.

3. Determine the Maximum LOCOMOTIVE LEVEL at 50 ft. ($L_{L,50}$) for $V \leq 20$ mph

$$\text{use } L_{L,50} = 83.6 + 0.15 \frac{n}{e} \quad (\text{dBA})$$

for $V > 20$ mph

$$\text{use } L_{L,50} = 94.8 + 23.5 \log \frac{V}{60} + 0.15 \frac{n}{e} \quad (\text{dBA})$$

4. Determine the MAXIMUM LOCOMOTIVE LEVEL at distance d(ft.)

$$(L_{L,d})$$

$$L_{L,d} = L_{L,50} + 20 \log \left(\frac{50}{d} \right) \text{ dBA}$$

5. Determine the Locomotive L_{eq} at d ft. ($L_{eq,L}$)

$$L_{eq,L} = L_{L,d} + 10 \log \left(\frac{d}{55} \right) + 3 \text{ dBA}$$

($L_{eq,L}$ turns out to be higher than expected as the time of the pass-by will be taken as the time for which the locomotive is in front of the observer. 55 ft. is a representative length for a locomotive.

6. Determine the Locomotive Time (T_L)

$$T_L = e \cdot N \cdot \frac{55 \cdot 15}{V \cdot 22} \text{ (seconds)}$$

7. Determine the Wheel/Rail Level at 50 ft. ($L_{w,50}$)

$$L_{w,50} = 87.8 + 25.7 \log \frac{V}{60} \text{ (dBA)}$$

8. Determine the Wheel/Rail L_{eq} at distance d(ft.) ($L_{eq,w}$)

$$L_{eq,w} = L_{w,50} + 10 \log \frac{50}{d} - 5 \log \left(1 + 4 \left(\frac{d}{57n} \right)^2 \right)$$

(the final term will be negligible if $d \leq \frac{1}{4} \cdot 57n$).

9. Determine the Wheel/Rail Time (T_w)

$$T_w = n \cdot N \cdot \frac{57 \cdot 15}{V \cdot 22} \text{ (seconds)}$$

(57 ft. is a representative length for each car).

10. Determine the total L_{eq} over the time period of interest - H (in hours);

Where H = 24 for a 24 hour L_{eq}

16 for a daytime L_{eq}

8 for a night time L_{eq}

$$L_{eq} = 10 \log \frac{1}{H \cdot 3600} \left\{ (10^{0.1 L_{eq,L}}) T_L + (10^{0.1 L_{eq,w}}) T_w \right\} \text{ (dBA)}$$

NOTE: If the different types of trains are operating at different speeds, the calculations must be performed separately for each type.

If, for example, we are predicting the levels for two types of trains - Freight and Passenger operating at different speeds - the calculations must be performed twice - once for each type of train.

V.2.A.2.4. EXAMPLE

Information given:

N = number of trains per day (07:00 to 23:00 hours) - 10

V = speed of trains = 40 mph

n = number of cars per train = 100 cars

d = distance = 200 feet

Assumed number of locomotives (e) = 3

1. MAXIMUM LOCOMOTIVE LEVEL at 50 ft. ($L_{L,50}$)

as V = 40 mph

$$\text{use } L_{L,50} = 94.8 + 23.5 \log \frac{V}{60} + 0.15 \frac{n}{e}$$

$$= 94.8 + 23.5 \log \frac{40}{60} + 0.15 \left(\frac{100}{3} \right)$$

$$= 94.8 - 4.14 + 5$$

$$L_{L,50} = 95.66 \text{ (dBA)} \rightarrow$$

2. MAXIMUM LOCOMOTIVE LEVEL at d = 200 feet

$$L_{L,d} = L_{L,50} + 20 \log \left(\frac{50}{d} \right)$$

$$= 95.66 + 20 \log \left(\frac{50}{200} \right)$$

$$= 95.66 + 20 \log 0.25$$

$$= 95.66 + 20(-0.60)$$

$$= 95.66 - 12.04$$

$$L_{L,d} = 83.62 \text{ (dBA)} \rightarrow$$

3. LOCOMOTIVE L_{eq} at $d = 200$ ft. ($L_{eq,L}$)

$$\begin{aligned}
 L_{eq,L} &= 83.62 + 10 \log \left(\frac{200}{55} \right) + 3 \\
 &= 83.62 + 10 \log 3.64 + 3 \\
 &= 83.62 + 5.61 + 3 \\
 &= 92.23 \\
 L_{eq,L} &= 92.23 \text{ (dBA)} \quad \longrightarrow
 \end{aligned}$$

4. LOCOMOTIVE TIME (T_L)

$$\begin{aligned}
 T_L &= e \cdot N \cdot \frac{55}{V} \cdot \frac{15}{22} \\
 &= 3 \cdot 10 \cdot \frac{55}{40} \cdot \frac{15}{22} \\
 &= 30 \cdot 1.38 \cdot 0.68 = 28.23 \\
 T_L &= 28.23 \text{ (seconds)} \quad \longrightarrow
 \end{aligned}$$

5. WHEEL-RAIL LEVEL AT 50 feet ($L_{w,50}$)

$$\begin{aligned}
 L_{w,50} &= 87.8 + 25.7 \log \frac{V}{60} \\
 &= 87.8 + 25.7 \log \frac{40}{60} \\
 &= 87.8 - 4.53 = 83.27 \\
 L_{w,50} &= 83.27 \text{ (dBA)} \quad \longrightarrow
 \end{aligned}$$

6. WHEEL-RAIL L_{eq} at $d = 200$ ft. ($L_{eq,w}$)

$$L_{eq,w} = L_{w,50} + \log \frac{50}{d} - 5 \log \left(1 + 4 \left(\frac{d}{57n} \right)^2 \right)$$

as $d = 200 < \frac{1}{4} (57(100))$
the last term is negligible

$$\begin{aligned}
 L_{eq,w} &= 83.27 + 10 \log \frac{50}{200} \\
 &= 83.27 - 6.02 = 77.25 \\
 L_{eq,w} &= 77.25 \text{ (dBA)} \quad \longrightarrow
 \end{aligned}$$

7. WHEEL-RAIL TIME (T_w)

$$T_w = n N \frac{57}{V} \frac{15}{22}$$

$$= 100 \cdot 10 \cdot \frac{57}{40} \cdot \frac{15}{22} = 1000 \cdot 1.43 \cdot 0.68 = 972.40$$

$$T_w = 972.40 \text{ (seconds)}$$

8. DETERMINE THE TOTAL L_{eq} over the 16 hour daytime period using:

$$L_{eq} = 10 \log \frac{1}{16 \cdot 3600} \left\{ 10^{0.1 L_{eq} T_L} + 10^{0.1 L_{eq,w} T_w} \right\}$$

$$= 10 \log \frac{1}{16 \cdot 3600} \left\{ 10^{0.1(92.23) \cdot 28.23} + 10^{0.1(77.25) \cdot 972.40} \right\}$$

$$= 10 \log \frac{1}{57600} \left\{ 10^{9.22} \cdot 28.23 + 10^{7.73} \cdot 972.40 \right\}$$

$$= 10 \log 1.74 \times 10^5 \left\{ 4.671 \times 10^{10} + 5.222 \times 10^{10} \right\}$$

$$= 10 \log 1717534.7$$

$$= 10(6.235)$$

$$= 62.35$$

Therefore, the daytime L_{eq} at a distance of 200 feet from the tracks with the above train operations is 62 dBA.

When compared to the daytime sound level limit for outdoor recreational areas of $L_{eq} = 55$ dBA, the excess is 7 dB.

V.2.A.2.5. Notes of the Use of the Train Noise Prediction Method

1. The prediction method assumes that the railway tracks are at grade.
2. The prediction method assumes that there is a direct line of sight between the railway tracks and the receiver.
3. The prediction method should not be used for source - receiver distances greater than 1000 feet.

V.2.A.2.6. Other Train Noise Prediction Methods

(i) "New Housing and Road and Rail Noise" (Draft 2)

Central Mortgage and Housing Corporation

The Rail Noise portion of the document contains a number of tables which give the equivalent energy continuous sound level (L_{eq}) of engine, wheel-rail and even whistle noise levels for trains at a reference distance and speed. Other Tables contain corrections to be applied to the reference levels for other distances and speeds.

The noise levels for the various components (engine, wheel-rail, etc.) are combined to provide a prediction of the 24 hour L_{eq} noise levels due to train passbys.

The L_{eq} sound levels in these Tables were obtained by using the semi-empirical train pass-by noise profile model developed by the Noise Pollution Control Section.

V.2.A.2.7. Simplified - Train Noise Model - Work Sheet Method

This version of the train noise prediction method is a much simplified version of the method outlined in V.2.A.2.4. This work sheet method which uses a number of graphs to determine the noise levels reduces the number of calculations to a minimum. The same information - in terms of train information - is required for this work sheet method as was required in V.2.A.2.4.

V.2.A.2.8. EXAMPLE of a Train Noise Prediction - Using the Worksheet Method

In V.2.A.2.4. we used the 'detailed' train noise method to calculate the noise levels from train passbys. We will now use the train information from that example to show how the worksheet method can be used to predict the noise levels.

1. Information required:

- Speed of the trains V (mph)
- Number of trains, N in the time period of interest, H (hours)
- Number of cars per train, n
- Distance from the track centreline, d (ft.)
- In this example (V.2.A.2.4.)

$V = 40$ mph

$N = 10$ trains during the daytime period ($H = 16$ Hours)

$n = 100$ cars

$d = 200$ ft.

SIMPLIFIED TRAIN NOISE MODEL WORKSHEET

1. Information required:

- Speed of the trains, V (mph) = **40** mph
- No. of trains, N= **10** in time period of interest, H = **16** hours
- No. of cars per train, n = **100**
- Distance from track centreline, d (ft.) = **200** feet.

2. Estimate Number of Locomotives per train (e)

- For
- | | |
|-------------------|---------|
| $0 < n \leq 35$ | $e = 1$ |
| $35 < n \leq 70$ | $e = 2$ |
| $70 < n \leq 105$ | $e = 3$ |
| $105 < n$ | $e = 4$ |

$$\therefore e = \mathbf{3}$$

3. Estimate Locomotive Level at 50 ft.

- Using Graph 1: for V = **40** mph
Locomotive Sound level at 50 ft. = **93.2** dBA

4. Estimate Locomotive Loading Correction

- For n = **100** e = **3** from Step 2
 $\frac{n}{e} = \mathbf{33.3}$

Using Graph 2:

- For $\frac{n}{e} = \mathbf{33.3}$
Loading Correction = **5.0** dBA

5. Estimate Final Locomotive Level at 50 ft.

- Locomotive Level = **93.2** dBA from Step 3
Loading Correction = + **5.0** dBA from Step 4
Final Locomotive Level at 50 ft. = **98.2** dBA

6. Estimate Wheel/Rail Level at 50 ft.

Using Graph 3:

$$\begin{array}{rcl} \text{For } V & = & 40 \text{ mph} \\ \text{Wheel/Rail Level at 50 ft.} & = & 82 \text{ dBA} \end{array}$$

7. Estimate Duration Corrections for Locomotive and Wheel/Rail

(a) Locomotive

$$\begin{array}{rcl} \text{For } V & = & 40 \text{ mph} \\ N & = & 10 \\ \text{and } e & = & 3 \quad \text{from Step 2} \\ \frac{N e}{V} & = & \frac{10 \times 3}{40} \\ \text{Using Graph 4:} \\ \frac{N e}{V} & = & 0.75 \\ \text{and } H & = & 16 \text{ hours} \\ \text{Locomotive Duration Correction} & = & -33 \text{ dBA} \end{array}$$

(b) Wheel Rail

$$\begin{array}{rcl} \text{For } V & = & 40 \text{ mph} \\ N & = & 10 \\ \text{and } n & = & 100 \\ \frac{N n}{V} & = & \frac{10 \times 100}{40} \\ \text{Using Graph 4:} \\ \text{For } \frac{N n}{V} & = & 25 \\ \text{and } H & = & 16 \text{ hours} \\ \text{Wheel/Rail Duration Correction} & = & -18 \text{ dBA} \end{array}$$

8. Correct Final Locomotive Level for Duration

$$\begin{array}{rcl} \text{Final Locomotive Level} & = & 98.2 \text{ dBA from Step 5} \\ \text{Locomotive Duration Correction} & = & -33 \text{ dBA from Step 7(a)} \\ \text{Corrected Locomotive Level at 50 ft.} & = & 65.2 \text{ dBA} \end{array}$$

9. Correct Wheel/Rail Level for Duration

Wheel/Rail Level = 82 dBA from Step 6
 Wheel/Rail Duration Correction = - 18 dBA from Step 7(b)
 Corrected Wheel/Rail Level at 50 ft. = 64 dBA

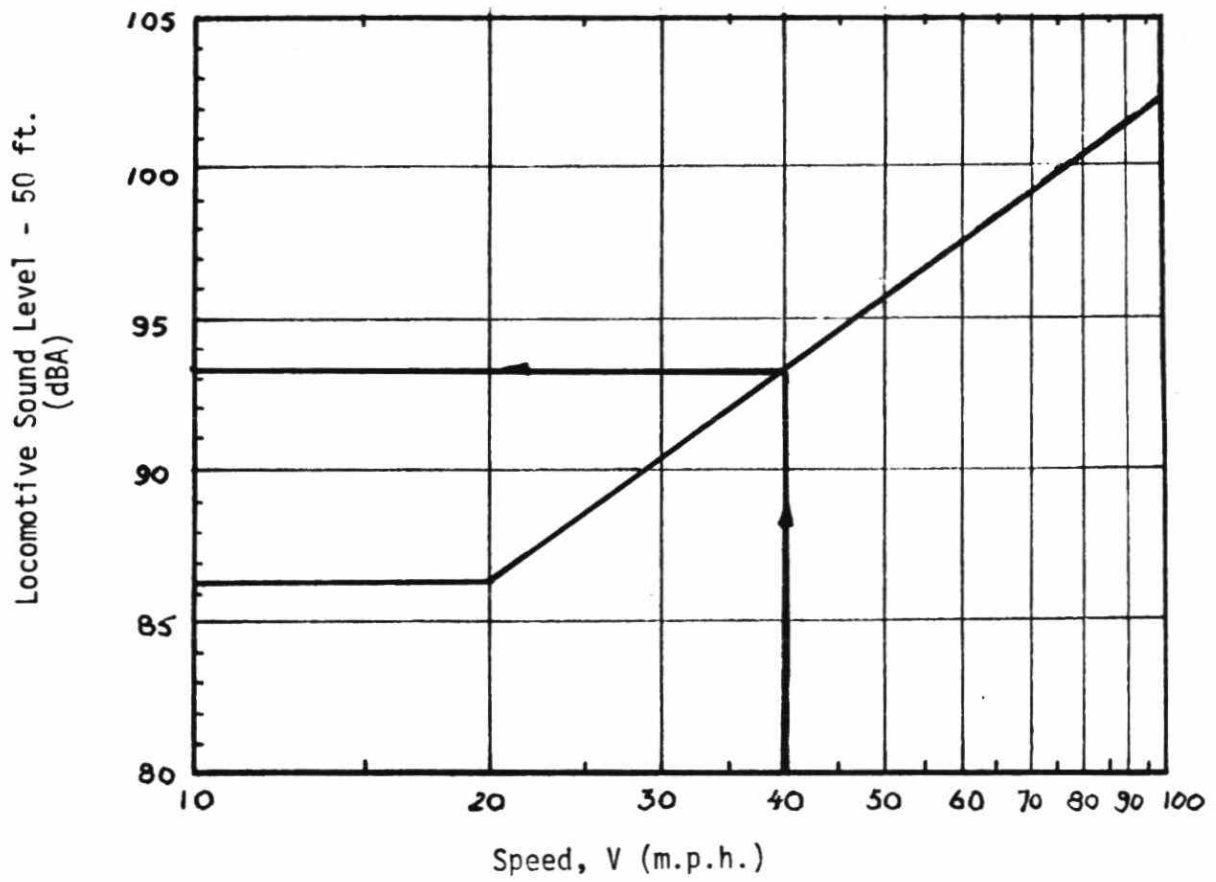
10. Combine Corrected Locomotive Level and Corrected Wheel/Rail Level

Corrected Locomotive Level = 65.2 dBA from Step 8
 Corrected Wheel/Rail Level = 64 dBA from Step 9
 Difference between Corrected Levels = 1.2 dBA
 Using Graph 5:
 For Difference between levels of 1.2 dBA
 Number of dBA to be Added to Higher Level = 2.35 dBA
 Higher of Corrected Locomotive Level or
 Corrected Wheel/Rail Level = 65.2 dBA
 Number of dBA to be added to Higher Level = +2.35 dBA
 Train Level at 50 ft. = 67.55 dBA

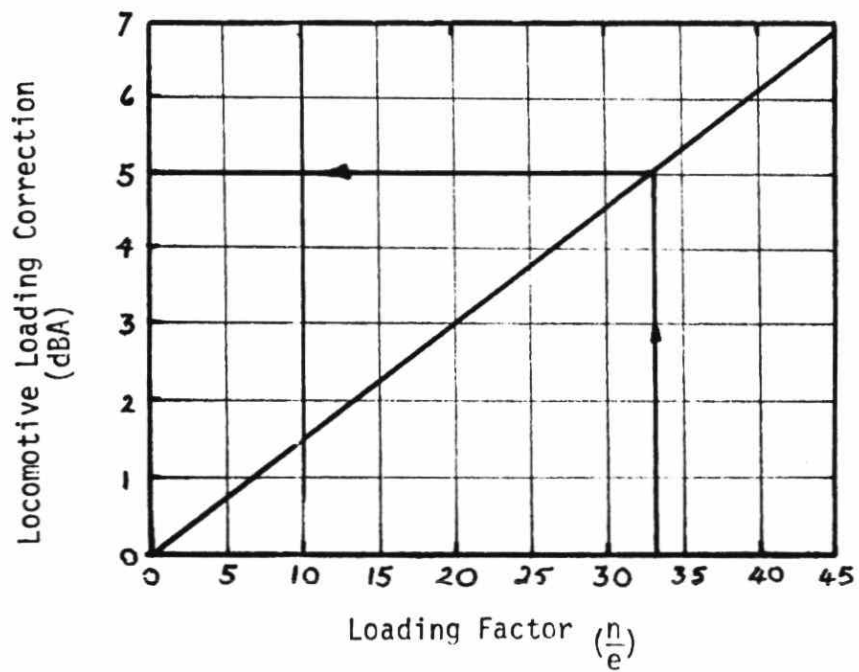
11. Correct Train Level for Distances Other Than 50 ft.

Using Graph 6:

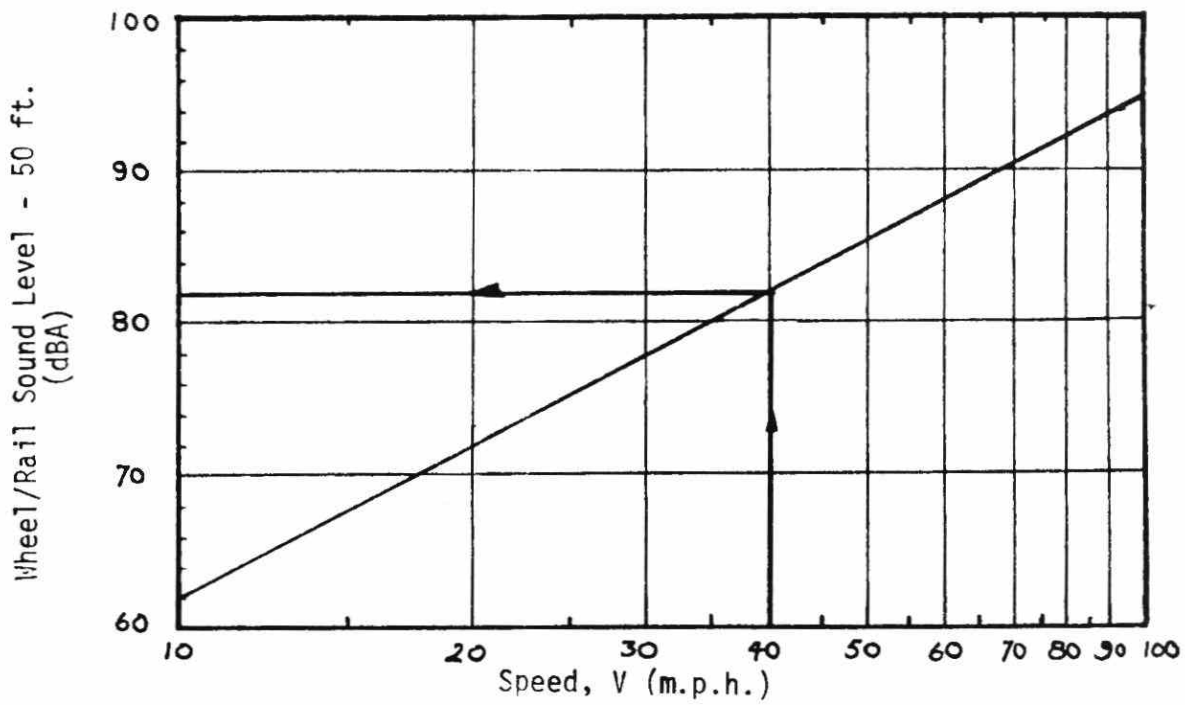
for Distance d = 200 feet
 Correction for distance = - 6 dBA (N.B. + for d < 50 feet)
 Train level at 50 ft. = 67.55
 Correction for Distance = - 6 dBA (N.B. + for d < 50 feet)
 Train noise L_{eq} = 61.55 dBA
 = 62 dBA



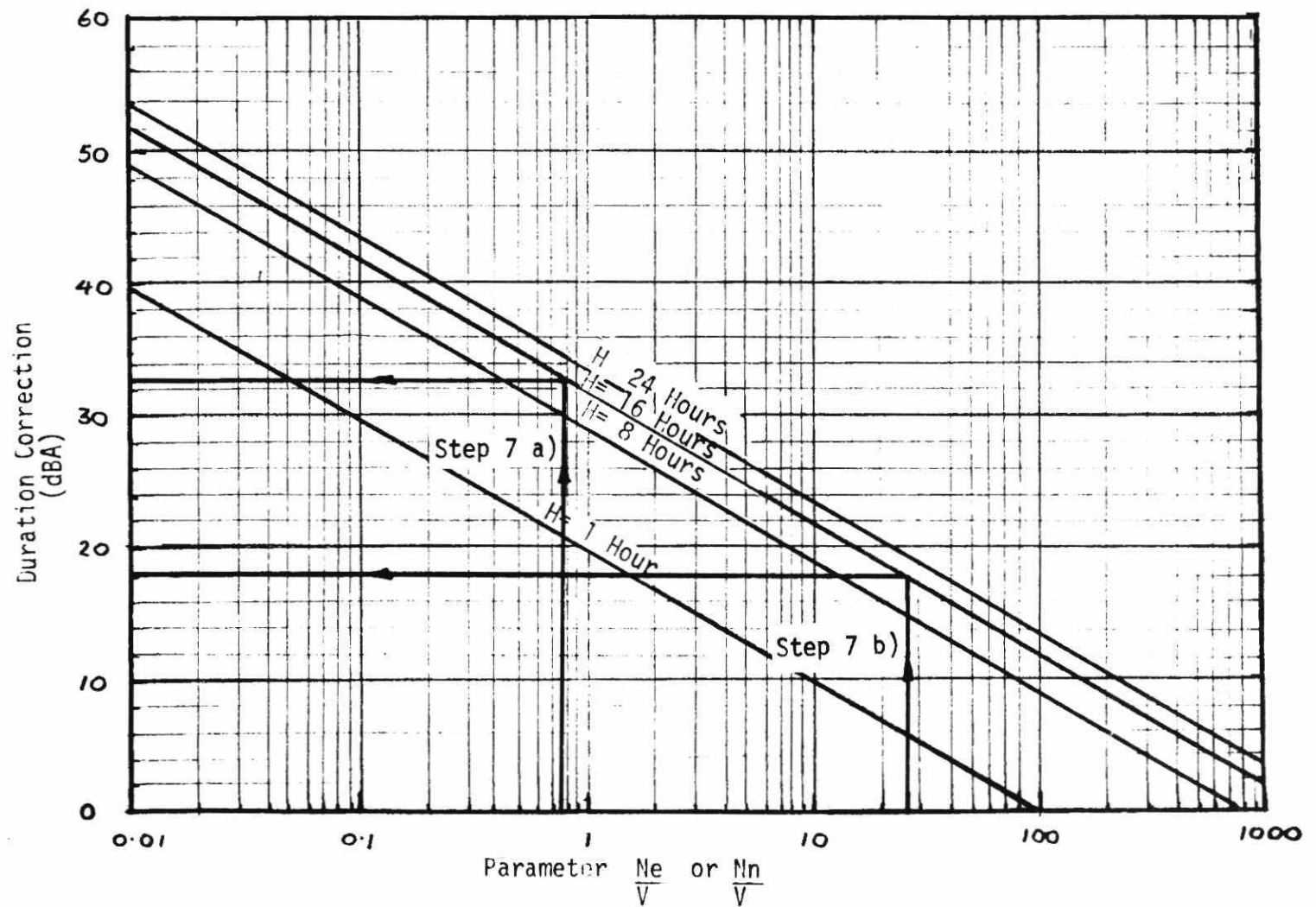
Graph 1: Locomotive Sound Level
Against Speed, V



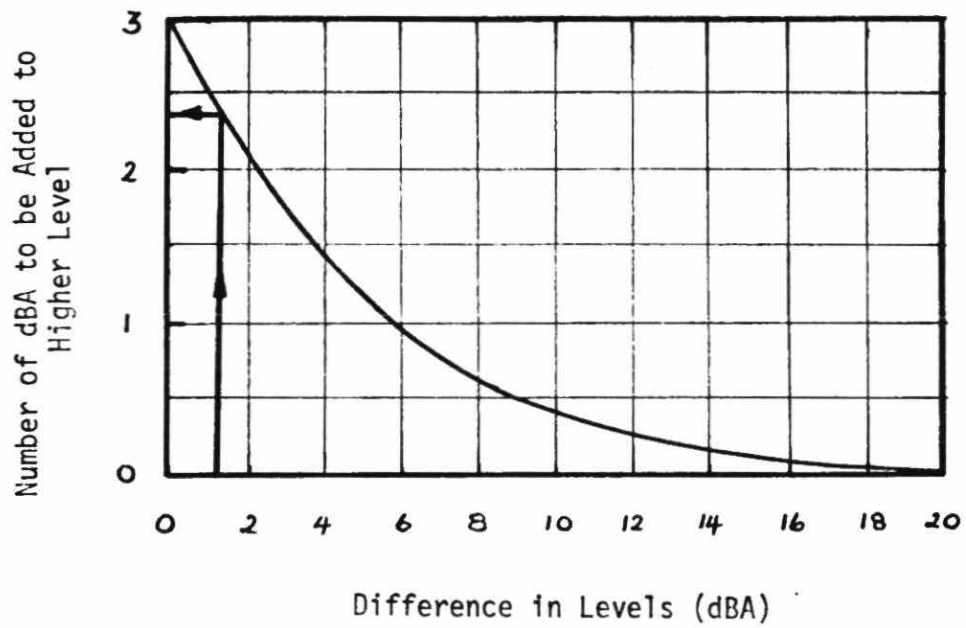
Graph 2: Locomotive Loading Correction
Against $\frac{n}{e}$



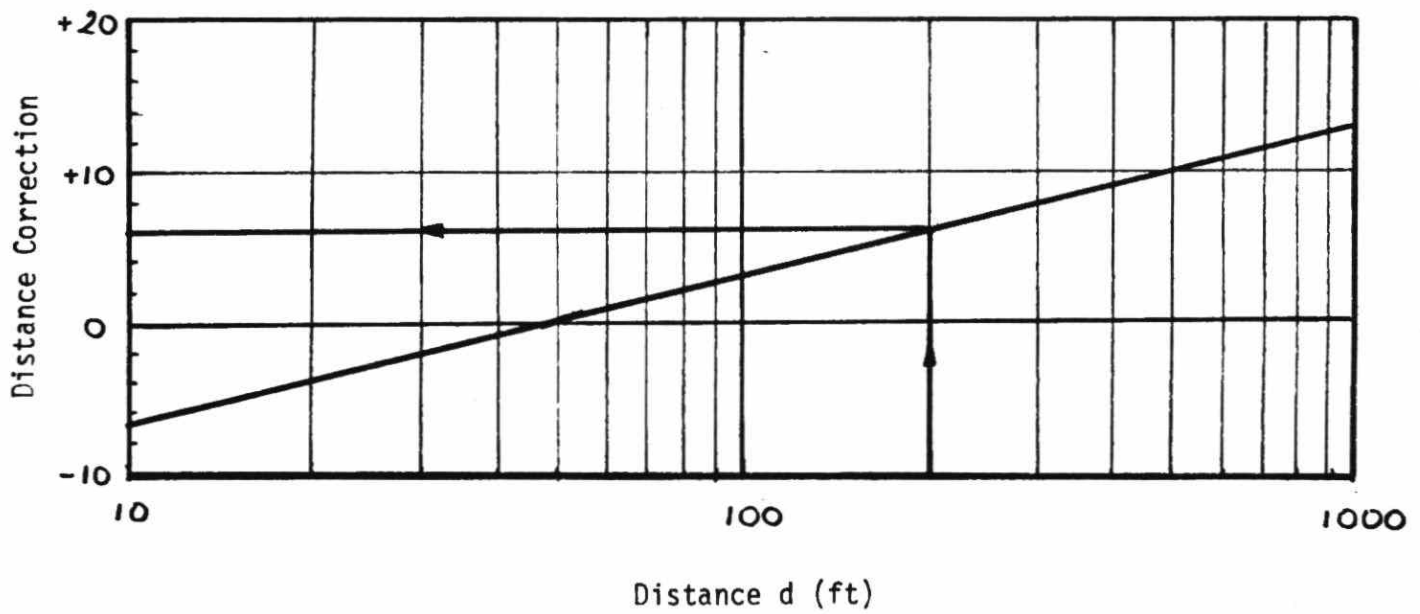
Graph 3: Wheel/Rail Sound Level
Against Speed, V



Graph 4: Duration Correction Against
Parameter $\frac{N_e}{V}$ or $\frac{N_n}{V}$



Graph 5. dBA Addition Graph



Graph 6. Distance Correction Against Distance d (ft)

OBJECTIVES:

Trainees will be able to:

1. Explain what is meant by "Noise Control Measures" in conjunction with noise impact assessment;
 2. List the three steps involved in implementing noise control measures at a site;
 3. Indicate why noise control measures should be considered early in the subdivision planning process;
 4. Explain the various site planning related noise control measures;
 5. Explain the various ways in which an acoustical barrier can be employed as a noise control measure;
 6. Explain how architectural design can aid in providing noise control for a residential development;
 7. Explain the use of construction techniques as a noise control measure for new housing;
 8. Interpret the check-list of noise control measures;
 9. Explain with the help of case histories how the different control measures can be integrated into subdivision plans to develop an interesting and diverse residential development.
-

V.2.B.1. NOISE CONTROL MEASURES

The term "Noise Control Measures" in this discussion refers to the methods of lowering indoor and outdoor noise levels to acceptable limits in residential areas impacted by surface transportation and industrial sources of noise. Specific application of noise control measures to reduce roadway traffic noise is covered in the Road Traffic Noise Tables.* Most methods discussed below were evolved as a result of constant discussion with architects, planners and developers and are of proven practicability. Some of the techniques, however, are still in an exploratory stage and presented here merely as suggestions to those involved in planning new housing. In any case, no simple rules can be devised regarding application of specific measures to certain types of applications, and the discussion is kept general in scope. It should be noted that the following discussion does not apply to aircraft noise control which is taken up separately in Topic V.5.A.

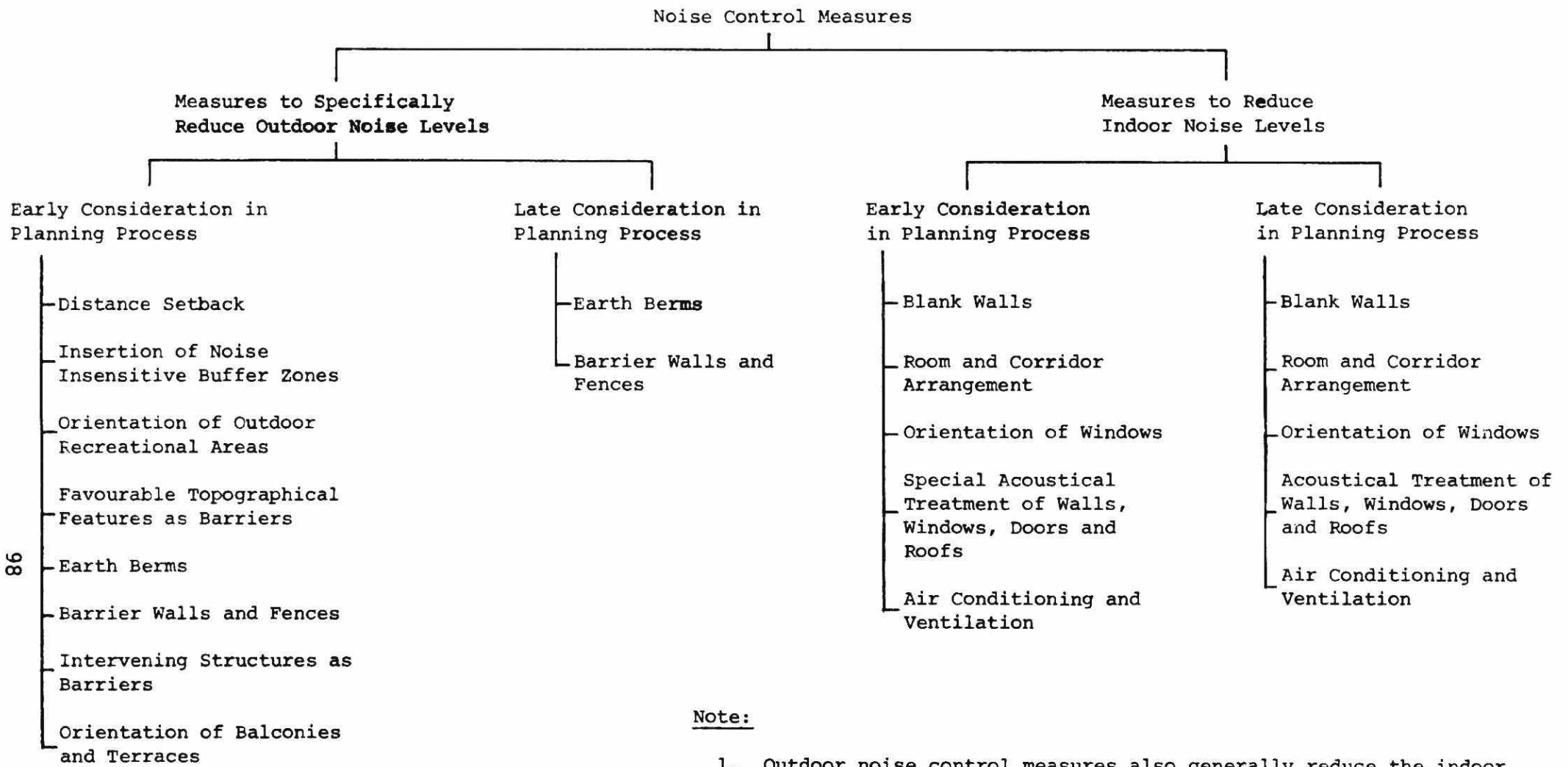
NOTE: The various measures for controlling noise in this Topic are primarily concerned with noise control at the Subdivision stage of planning. However, when considering new zoning, as in the construction of Official Plans, with respect to noise, the two most realistic and effective measures are those discussed under the titles: "Distance Setback" and "Insertion of Noise Insensitive Buffer Zone", later in Topic V.2.B.4.

V.2.B.2. THREE STEPS INVOLVED IN IMPLEMENTING NOISE CONTROL MEASURES

The process of implementing noise control measures for new housing can be viewed as a three-step process.

- Step 1: Determine noise levels at site;
- Step 2: Compare projected noise levels against design sound level limits;
- Step 3: Design noise control measures for excess over design sound level limits.

* Road Traffic Noise Tables, published by the Ontario Ministry of the Environment, 1977.



Note:

1. Outdoor noise control measures also generally reduce the indoor noise levels.
2. Measures considered during early planning process are generally more acceptable aesthetically and cost very little.

Table V.2.B.1: Indoor and Outdoor Noise Control Measures and Their Timing in the Subdivision Planning Process.

In step 1, the noise impact on the proposed residential development is determined by the use of prediction models and techniques covered in section V.2.A. However, when the subdivision geometry or topography is complex and the area is impacted by many different types of noises, prediction methods cannot be readily applied and measurement techniques give more reliable information.

Measured levels are projected to future years (usually 10 years hence) in order to fully appreciate the potential impact.

Having determined the future noise levels for the proposed site in step 2, these are compared against the outdoor sound level limits given in Topic V.1.D. and the excess over recommended limits is determined. Of course, if the levels at the site are lower than these limits, no noise control measures are required.

Step 3 involves selection of appropriate noise control measures depending on the following factors.

- (i) Required reduction of indoor and/or outdoor levels.
- (ii) Timing for considering noise control measures in the subdivision design process, i.e., early or late.
- (iii) Constraints or restrictions unique to the site.

V.2.B.3. SIGNIFICANCE OF TIMING IN CONSIDERING NOISE CONTROL MEASURES

The earlier discussion in Topic V.1.D. identified two different design sound level limits to be met in designing new housing, applicable to indoor noise levels and outdoor noise levels. Although the implementation of noise control measures outdoors also affects the levels achieved indoors; generally speaking, these measures can be viewed as relating to two separate applications. Table V.2.B.1. groups commonly used noise control measures under these two categories. Measures in the Table are also grouped on the basis of whether they can be considered during the early or late stages of planning the subdivision. The Table clearly indicates that the earlier noise control is considered during the process of subdivision design, the larger the selection of available control measures there will be to choose from. Thus, early consideration of noise control can conceivably reduce the costs of noise control by selecting measures which are most economical and also at the same time satisfy aesthetic and other requirements.

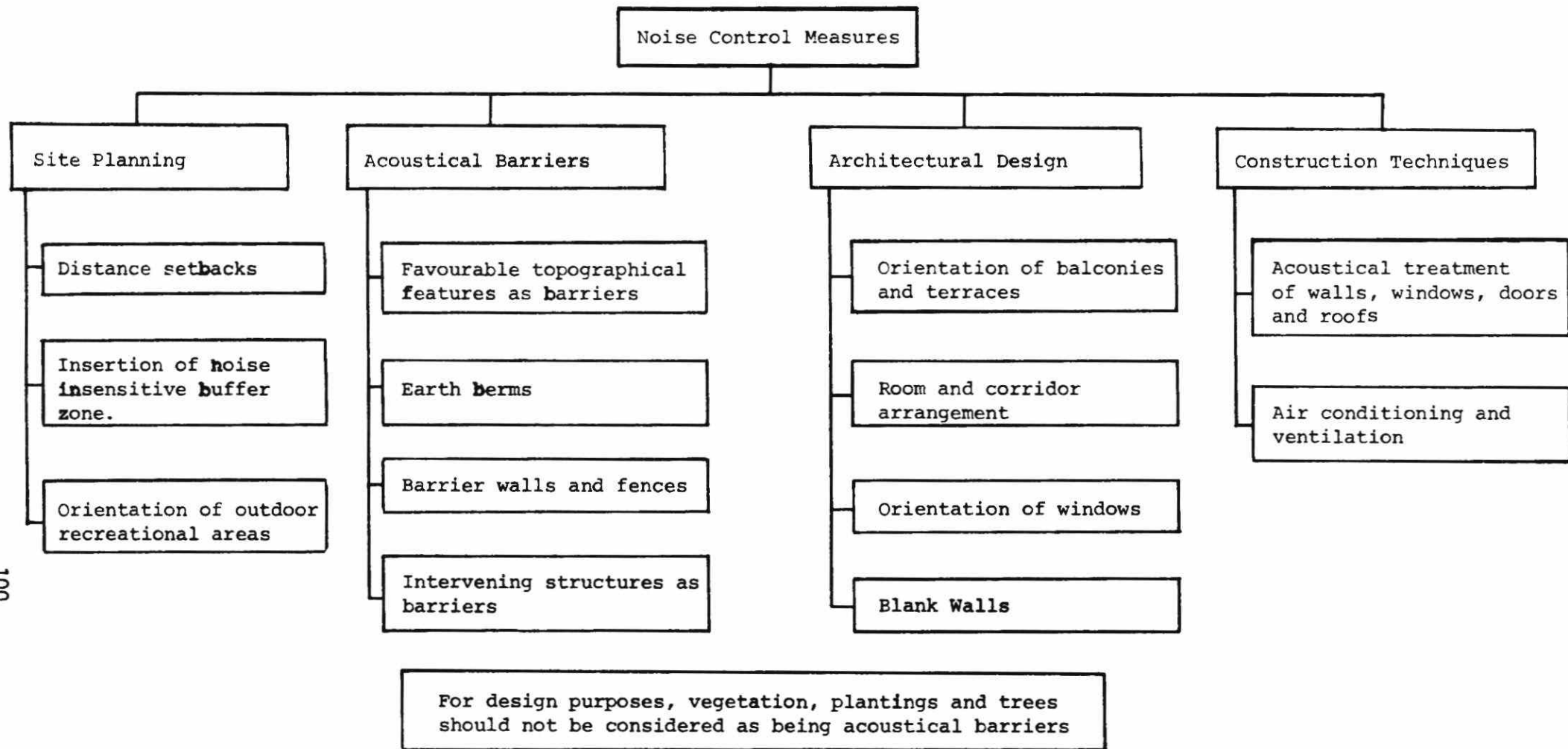


Table V.2.B.2.: Summary of Noise Control Measures Applicable to Design of New Housing

Having learned the significance of the indoor and outdoor measures, and the importance of considering noise control early in the planning process, we go on to discuss the measures themselves.

Physical methods to reduce noise impacts on new housing can be grouped into four major categories, as shown in Table V.2.B.2.

1. acoustical site planning
2. acoustical barriers
3. acoustical architectural design
4. acoustical construction techniques

A discussion of each group now follows.

V.2.B.4. ACOUSTICAL SITE PLANNING TECHNIQUES AS NOISE CONTROL MEASURES

Site planning means making use of the natural shape of the site, favourable surroundings and zoning to reduce the noise impact on proposed housing. The natural features of the site can only be utilized in reducing noise levels if noise control is considered early in the planning of the subdivision, when the flexibility is still available. In general, site planning measures are economical and very effective. Experience indicates that prudent and cost-conscious planners and architects almost never fail to capitalize on them. Some of the recommended site planning measures are discussed below:

V.2.B.4.1. Distance Setback

The physical separation between the noise source and the receiver is increased in this method to reduce outdoor noise levels. This method is most effective close to the noise source. For example, increasing the distance of a receiver from a highway from 50 feet to 100 feet would attenuate hourly L_{eq} levels by approximately 4 dBA. On the other hand, if the receiver were located at 200 feet; to get the same attenuation, the distance will have to be increased to 400 feet. Thus, a 4 dB attenuation at 50 feet requires an additional setback of 50 feet (100 feet - 50 feet), and at a distance of 200 feet requires another setback of 200 feet (400 feet - 200 feet). This is because the noise level varies logarithmically with the distance.

Although, the above illustration is for highway noise, the phenomenon also applies to railway noise.

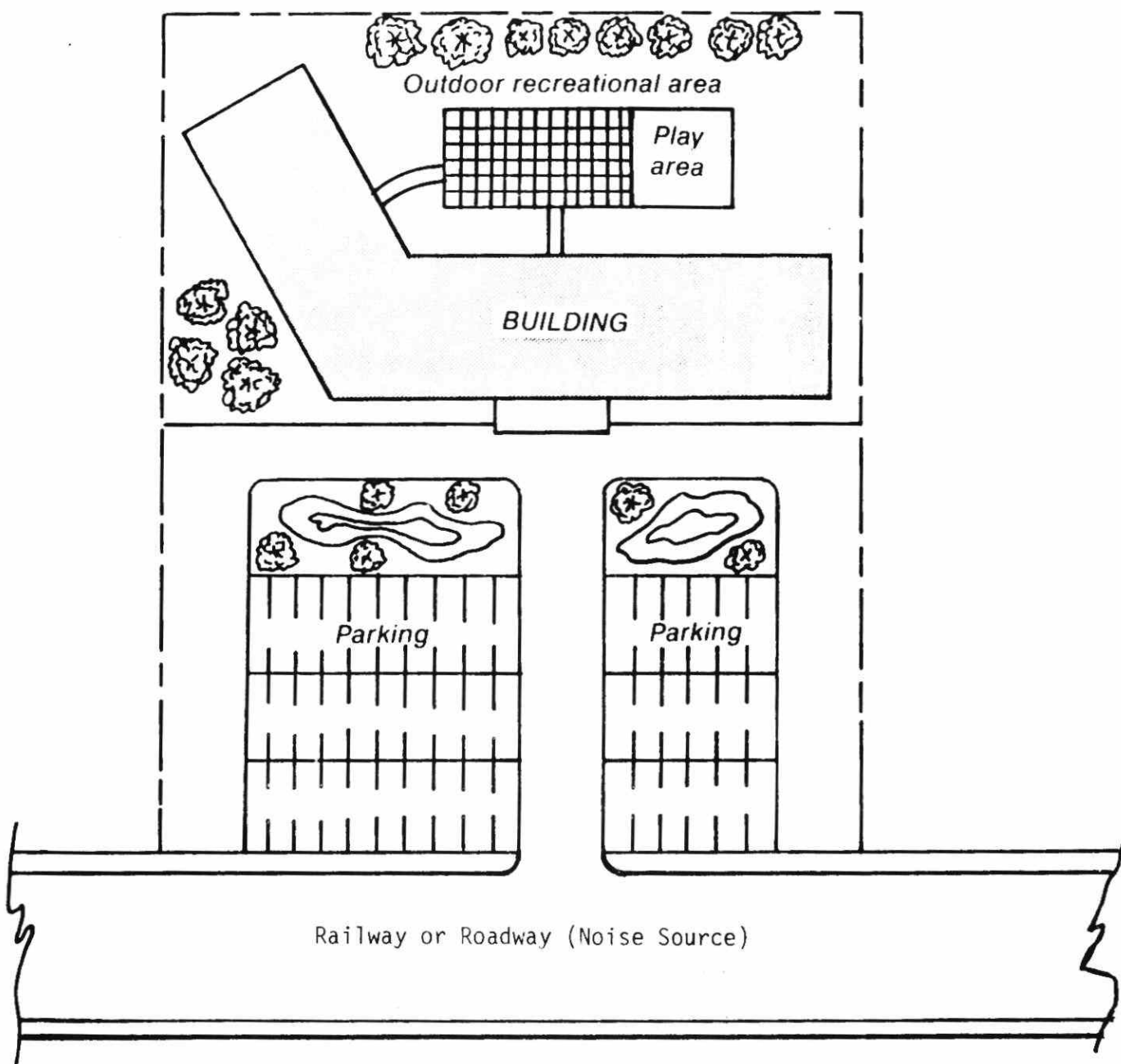


Figure V.2.B.1.: The Use of Parking Area as a Noise-Insensitive Buffer Zone

Noise reduction by the method of distance set-back is usually more practicable in rural areas where land costs are lower. In most urban areas, land is expensive and distance setback alone can rarely be afforded, unless the intervening land can be used for other compatible uses as will be discussed later.

Distance setback as a measure to reduce outdoor noise levels is, therefore, available only during the earliest of stages in a subdivision design when flexibility in planning design can still be exercised.

Distance setback is directly aimed at reducing outdoor levels.

V.2.B.4.2. Insertion of Noise-Insensitive Buffer Zones

The use of the distance setback method in urban areas is prohibitive because of high land costs. It can, however, be made feasible if the setback strip can be put to other useful applications. Noise control by the use of a buffer zone is based on this concept. This approach offers two advantages; firstly, the setback area is not wasted and, in fact, utilized for a compatible land-use. Secondly, additional shielding of the subdivision against noise is provided if the buffer zone utilization calls for tall and continuous structures. A discussion of this second advantage will be taken up under barrier noise control measures covered in Section V.2.B.5.

Typical land uses of the buffer strip are subdivision parking, parks, green belts and, in some cases, basketball and tennis courts. One such application illustrated in Figure V.2.B.1., the option to reduce outdoor noise levels by creating a buffer zone, is available only during the early planning stage of the subdivision.

NOTE: The various measures for controlling noise in this Topic are primarily concerned with noise control at the Subdivision stage of planning. However, when considering new zoning, as in the construction of Official Plans, with respect to noise, the two most realistic and effective measures are the two discussed above i.e.: "Distance Setback" and Insertion of Noise Buffer Zones".



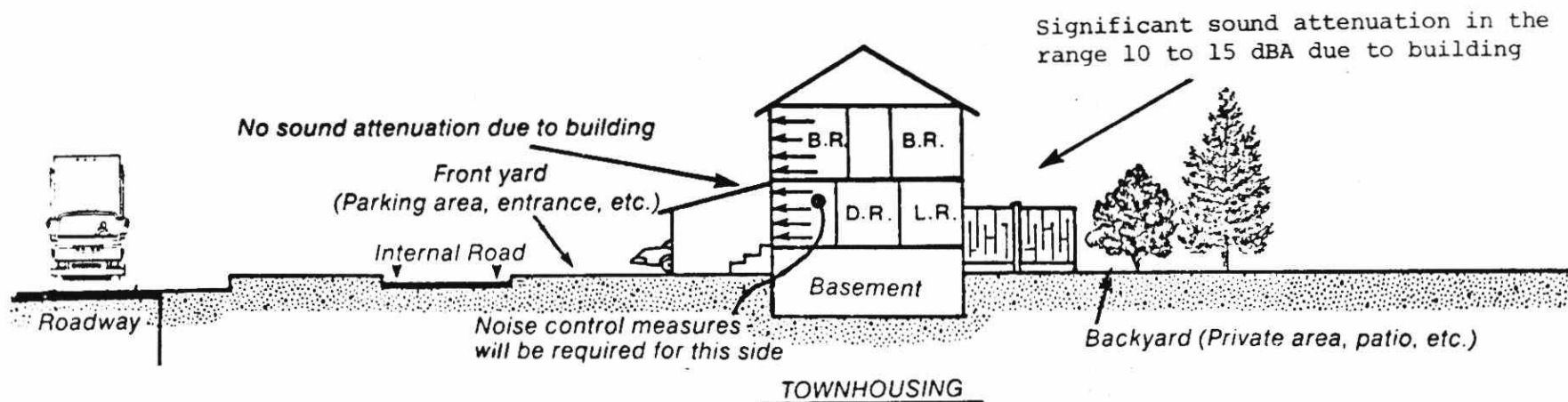


Figure V.2.B.2.: Recreational Area (Backyard) Shielded by the Townhouse Structure

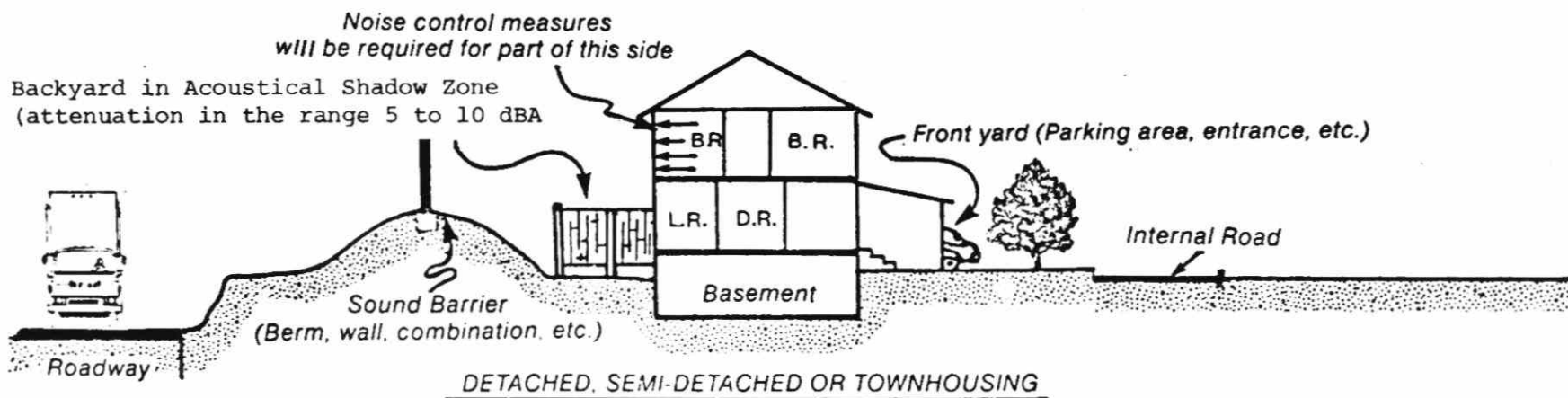


Figure V.2.B.3.: Recreational Area (Backyard) Shielded by a Sound Barrier

V.2.B.4.3. Orientation of Outdoor Recreational Areas

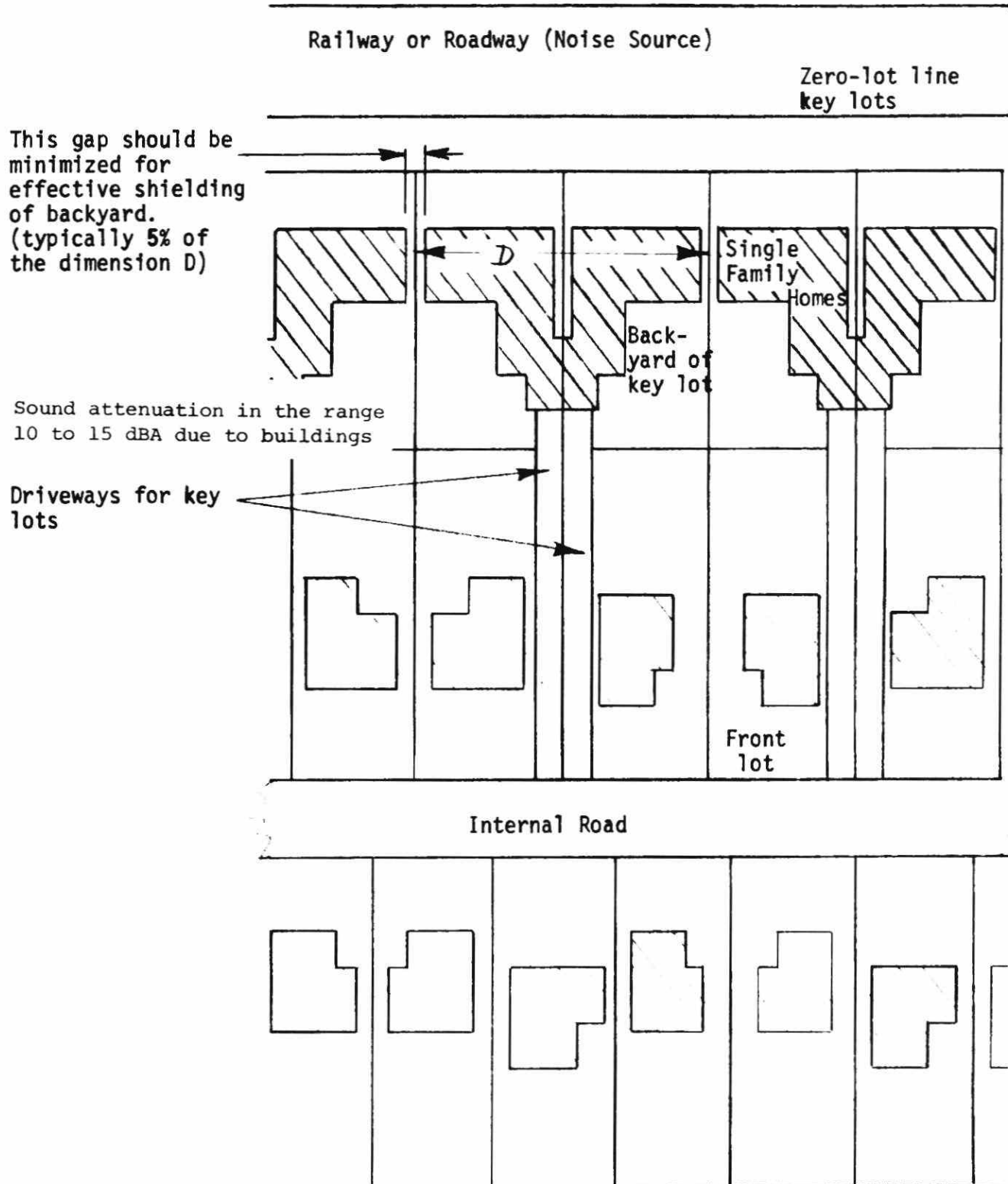
The requirement to provide quiet outdoor recreational areas for new residential development is clearly as important as ensuring low noise levels indoors.

The backyards of dwellings are customarily used as private areas for the enjoyment of the outdoors and for recreational activities such as relaxation, conversation, etc., and the front yard for parking. In this case, the house structure itself can act as a barrier between the noise source and the receiver by shielding the backyard from noise. Also, the shielding of the backyard is more effective for linkhousing, rowhousing or townhouses where the structure is continuous, parallel and close to the noise source. Short length structures of single family units are not really effective as barriers.

Two common ways of planning quiet recreational areas are listed below.

In one arrangement the front yard of the townhouse is located directly exposed to the noise source, and the backyard in the shadow zone behind the residence. Parking and entrance to the townhouse is provided through the front yard, as shown in Figure V.2.B.2. This application is known as single side use, internal road. Another way of arranging the recreational area is to interchange the front yard and the backyard in the above configuration and then protect the backyard from the noise source by the use of a berm or wall as shown in Figure V.2.B.3. The front yard is serviced by the internal road running parallel to the townhouses. The second arrangement is less efficient than the first one because of the added cost of erecting and maintaining the berm and because of aesthetic reasons. The function of a berm is performed by the townhouse structure itself in the first arrangement.

The methods of shielding the backyard as shown in Figures V.2.B.2. and V.2.B.3. are not without their problems. The concept of employing a continuous structure to shield backyards is a restrictive one, since only rowhousing or townhouses satisfy this requirement, precluding the use of single family homes in the first row. Planners also point out that the single side use of the internal road is inefficient and expensive because residences are located on one side of the road only. One answer to these problems is to use key lots for the exposed row.



Reproduced from the Key Lot Study for the Townsend Community Development Program, Ministry of Housing, by John Bousfield Associates, February, 1977.

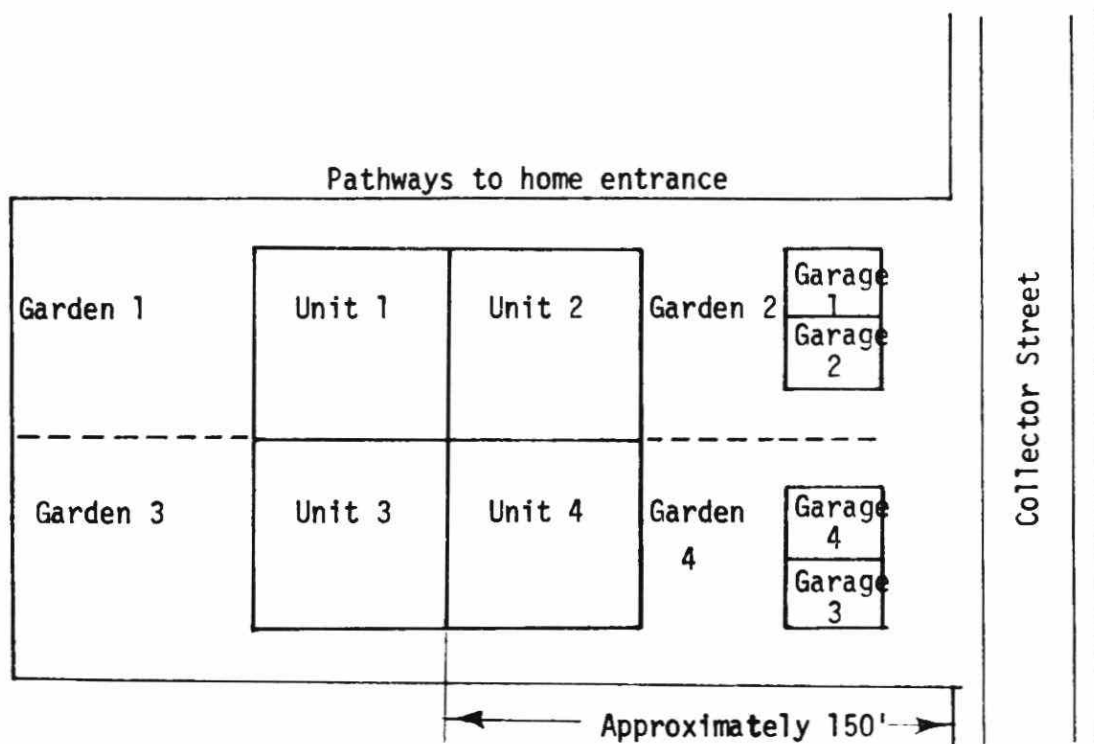
Figure V.2.B.4.: Single Family Homes (shown shaded) Shielding Recreational Area.

Key lots are basically the back lots located behind the front lots and connected to the public street by a long and narrow driveway for vehicular and pedestrian access. In Figure V.2.B.4. the local street serves the key lots as well as the front lots. Zero lot line single family homes on key lots provide a near continuous structure shielding the backyards from the noise source. For effective noise control, gaps between the single family homes should be minimized. Finally, it must be recognized that because of the gaps being present in the exposed row, noise reduction in the backyards of key lots will be less than that provided by a continuous row of townhouses and/or rowhouses.

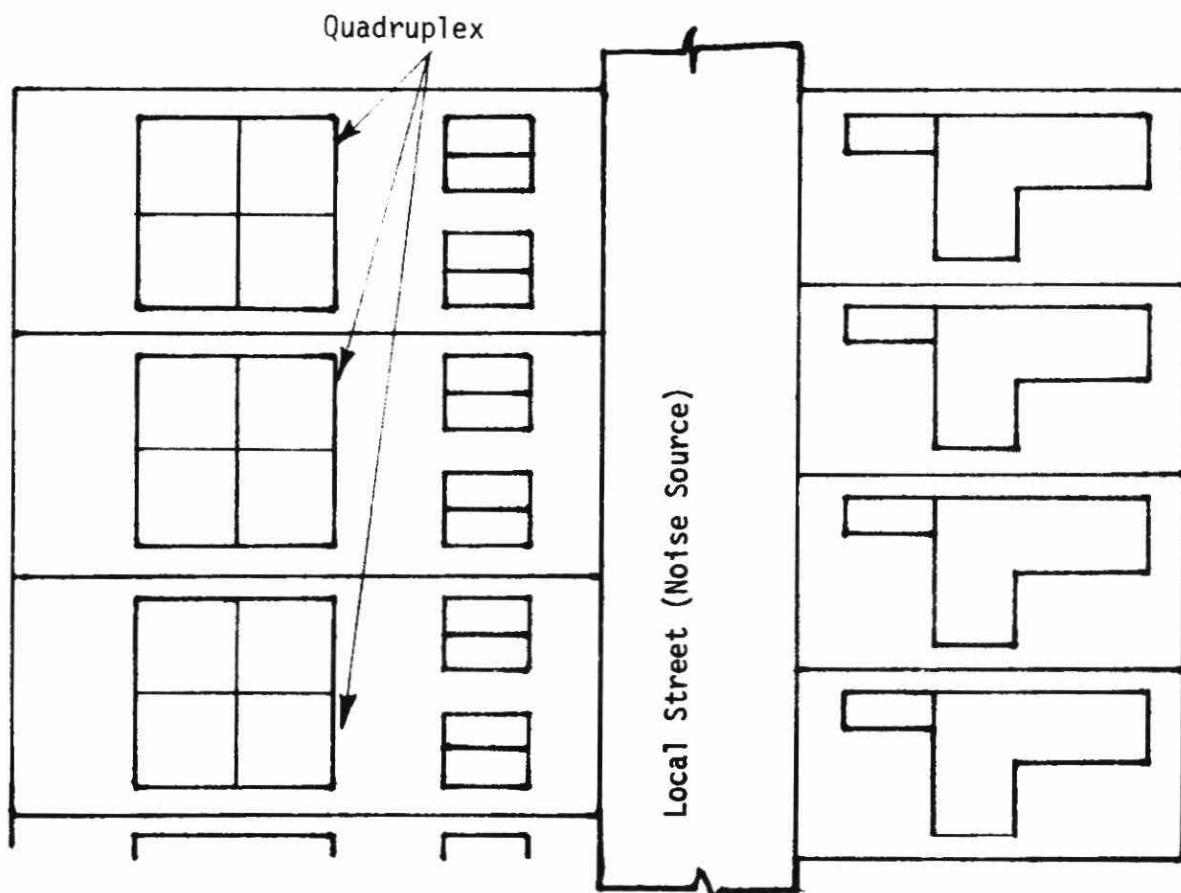
It is reported* that in spite of the relatively long driveways which impose an additional burden of snow removal on the occupant, per unit servicing costs for key lots are actually lower when compared with those of a conventional subdivision. The increased number of driveways and access roads, however, reduces the number of spots available for street parking. Further, it is harder for visitors to identify a key lot driveway. The planner must judge if the noise problem at the site is serious enough to be resolved at the cost of introducing these inconveniences.

Sale quadruplex, a new type of housing not widely used at present, is a variation of key lot principle.* This concept minimizes the length of driveways, and provides a more direct access to the units as compared to key lots. In this arrangement, each lot is divided in four semi-detached dwellings. The gardens of the two front units are shielded from the noise source by the garage building, and the recreational areas of the rear units are well protected and far removed from noise as shown in Figure V.2.B.5. However, because of the finite dimensions of the garage, the reduction of levels in the front yard cannot be expected to be large. As a result, the application of the quadruplex is limited to situations where only a slight noise reduction is required, such as for a lot exposed to a busy local street.

* Key Lot Study for the Townsend Community Development Program, Ministry of Housing, prepared by John Bousfield Associates, February 1977.



Sale Quadruplex Type of Housing



Based on the Key Lot Study for the
Townsend Community Development Program

Figure V.2.B.5.: Sale Quadruplex to Shield Recreational Areas
From a Busy Local Street

Figure V.2.B.6. illustrates four of the ways of shielding recreational areas of apartment buildings, which are being proposed in the St. Lawrence Housing Project, Toronto. In all four cases, the building shields the exterior recreation areas from the noise source. Another variation in which the recreational area of an apartment building is located on the third floor and can also be used as a sun-deck, is shown in Figure V.2.B.6.(c). The concept of shielding backyards is not just confined to more conventional forms of housing such as townhouses, rowhouses and detached homes, but also extends to other types of dwellings. In Figure V.2.B.7. the backyard of a duplex is divided into two separate areas depthwise, one being used by the occupants living upstairs and the other by the occupants on the main floor.

The planning to lower noise levels in recreational areas by orienting the recreational areas and residences must commence early in the subdivision design process. The extensive use of this method by planners is a good indicator of the wide range of possible applications and economics of controlling noise.

V.2.B.5. ACOUSTICAL BARRIERS AS A NOISE CONTROL MEASURE:

An acoustical barrier is a physical structure, planned or natural, placed between a noise source and the noise sensitive area where reduced noise levels are required.

Although well designed barriers are known to be very effective in reducing noise levels, they should be considered as a secondary measure after various other site planning measures have been considered for the site and have failed to reduce the outdoor levels to the design sound level limit.

Barriers are usually considered in those applications where outdoor noise levels cannot be reduced by other methods.

Since certain barriers such as berms require valuable additional land, it is good practice to consider them early in the planning process. However, barrier walls can still be designed late into the subdivision planning process, if necessary.

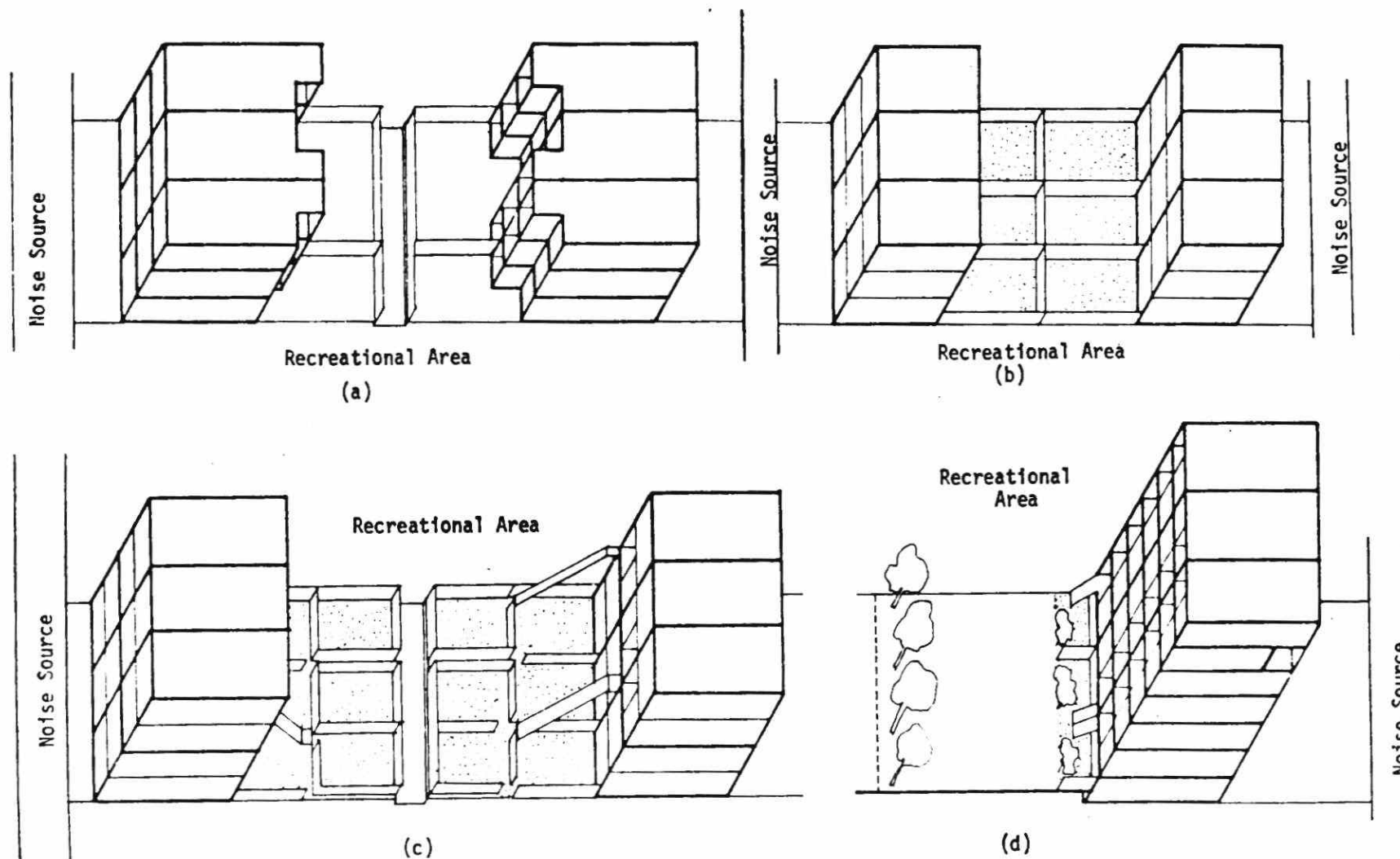
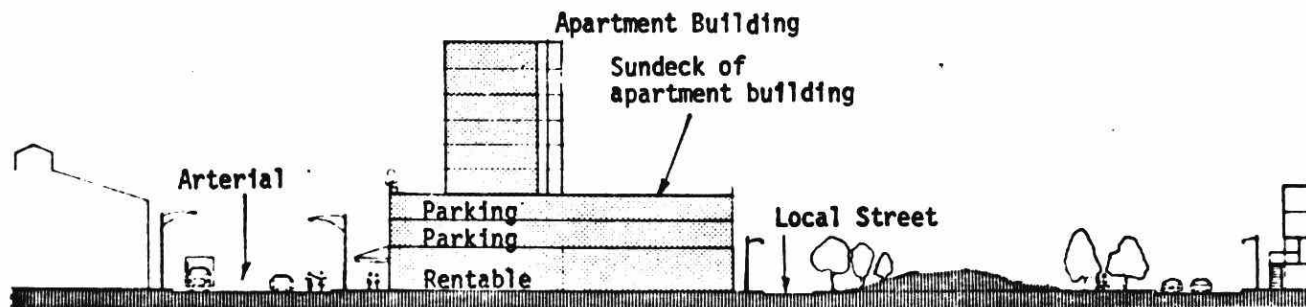


Figure V.2.B.6.: Shielding the Recreational Areas of Apartment Buildings Proposed in St. Lawrence Project, Toronto

The subject of barriers is discussed in more detail later in Topic V.2.C., and is examined in a Workshop Session in V.3.C. & D., but some observations with respect to the use of barriers are in order here:

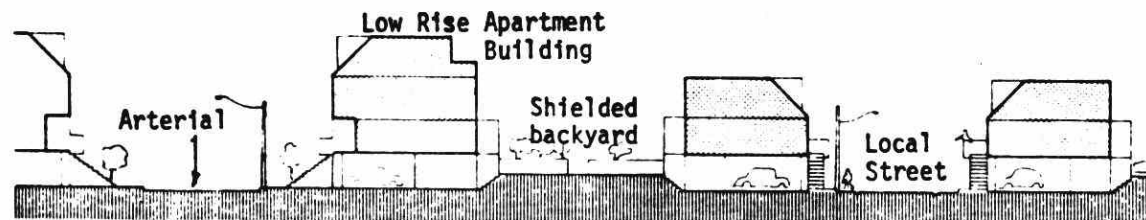
- (i) To be effective, barriers must be long and continuous, encircling or surrounding the area to be protected so that sound waves do not pass around the ends. To ensure this the ends of the barrier are extended well beyond the noise sensitive area. The barriers must be solid, free from gaps or holes and have adequate mass (not less than 4 lb./ft²).
- (ii) Noise level reduction achieved due to a barrier is dependent on the path-length difference between the source and the receiver. The difference between the direct distance in a straight line without a barrier, and the distance measured over the top of the proposed barrier. The situation is illustrated in Figure V.2.B.8. The barrier is most effective when it is erected either very close to the source or to the receiver. Another important design factor is the mass density of the barrier, higher reductions of noise levels correspond to denser barriers.
- (iii) To be effective, a barrier must be high enough to eliminate the direct line of sight between the source and receiver. Highest possible elevations of source and receiver should be considered in the design calculations. Figure V.2.B.9. illustrates this point for a receiver located at ground level as well as one at the first floor level.
- (iv) If the barrier is effectively designed, the noise problem can conceivably be eliminated for the rest of the site, thus making a large portion of the site available for upgraded residential use which would not have been possible otherwise due to the hostile noise environment. As an illustration, appropriately designed rowhousing acting as a barrier may make it possible for single family houses to be planned for the inner core of the subdivision without any special noise control measures. Thus, the effect of designing a barrier is to reduce the area impacted by excessive outdoor noise levels.



(a) Planning a Common Recreational Area of a High-Rise Building.



(b) Planning Recreational Area of a Duplex



(c) Planning Recreational Area of a Low Rise Apartment Building

These diagrams are reproduced from the reports on St. Lawrence Housing Project, The City of Toronto Housing Department.

Figure V.2.B.7.: Proposal to Protect Recreational Areas For Apartment Buildings and Duplexes for St. Lawrence Housing Project, Toronto

- (v) Safety must also be considered in selecting a barrier design. Structural stability and durability of the berm, servicing, maintenance and erection costs are some further important considerations.
- (vi) Some side advantages of acoustical barriers should be noted such as, privacy, providing visual screening, protection against salt, slush, debris and headlight glare. A qualitative discussion of different types of barriers follows below; barrier calculations and quantitative aspects of barrier design are covered in section V.2.C.

V.2.B.5.1. Topographical Features as Natural Barriers

Existing topographical features such as valleys or ravines at a residential site can quite often be successfully exploited to act as natural barriers. Two such applications where direct line of sight between the source and receiver is eliminated and noise levels reduced by the use of favourable site topography are illustrated in Figure V.2.B.10. In some cases topographical measures can be enhanced or wholly created at the site by excavating or landfilling or by lowering the road level.

Since the natural barrier utilizes the natural features at the site, it readily blends with the topography of a site and is aesthetically more desirable. Costs also tend to be generally smaller compared to those for the erection of berms or walls.

V.2.B.5.2. Earth Berms

An earth berm is a planned or deliberately created barrier usually made of a mound of earth running parallel to the noise source or the row of residences as shown in Figure V.2.B.11.

Some important features of an earth berm are summarized below:

- (i) Because of the sloping walls, the incident sound waves are deflected upwards and not towards the other side of the roadway as would be the case with vertical walls. This causes noise levels on the other side of the roadway to increase only slightly.

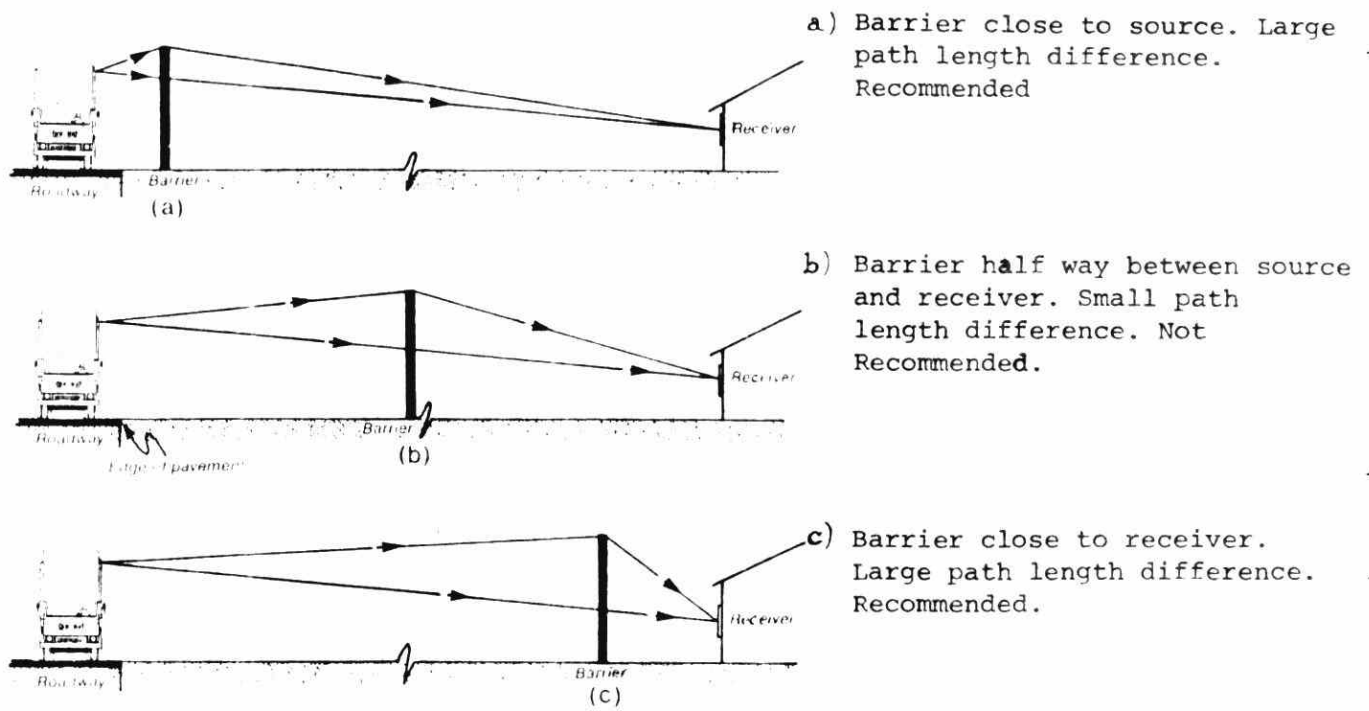


Figure V.2.B.8.: Possible Sound Barrier Locations with Respect to Receiver and Roadway

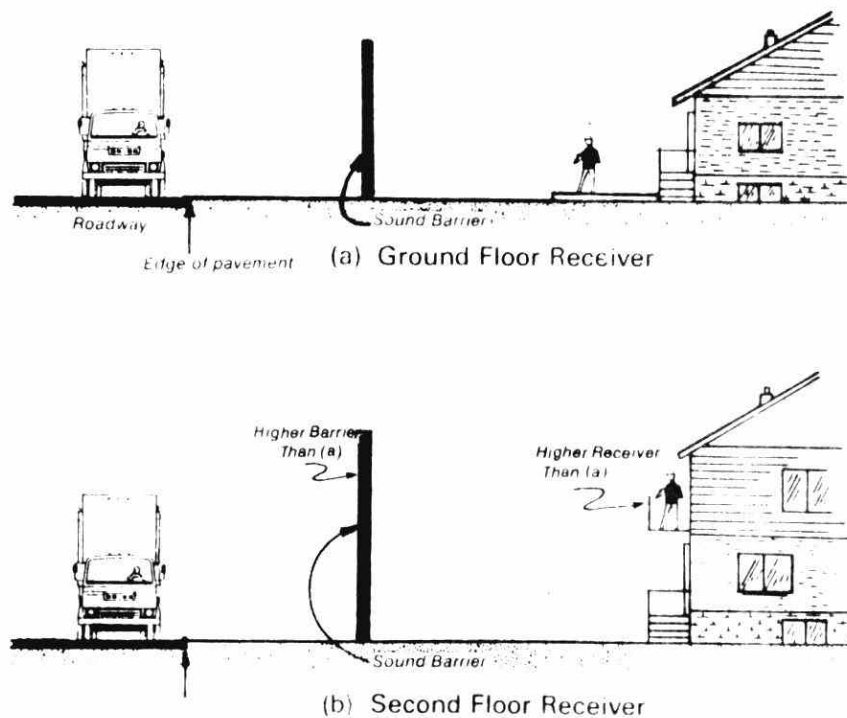


Figure V.2.B.9.: Barrier Height Required For Two Receiver Positions

- (ii) A berm provides a good absorptive surface compared to that offered by bare barrier walls, thus causing the levels due to the reflected sound waves to be lower.
- (iii) A berm easily meets the minimum mass density requirement of 4 lbs/ft².
- (iv) A berm can range up to 15 feet, or more, in height and still be designed to be satisfactory from an aesthetic viewpoint. Some reports cite 50 feet as being the upper limit in berm height construction.
- (v) The higher the berm, the greater the volume of earth required for its construction, and the wider its base, thus requiring more land for erection.

Since the building of a berm requires land space, provisions must be made for it in the early planning stages. A further point is that the shallow slope of a berm is aesthetically more acceptable, but also occupies more land and results in higher costs. High costs can be offset by successfully utilizing the slopes for various recreational purposes as shown in Figure V.2.B.12.

Earth berms are specifically addressed to the problem of lowering noise levels in outdoor recreational areas, although indoor levels are also reduced to the same extent.

Erection of berms as a control measure should be considered favourably if surplus earth were to become available during the construction of the subdivision at no cost. Cost of building berms should take account erection cost, maintenance expenses of cutting the grass on slopes and snow removal expenses, etc. Structural stability and durability are also major considerations with berms.

V.2.B.5.3. Barrier Walls and Fences

Barrier walls or fences offer the advantage of requiring a minimum of space, easy maintenance and a very strong physical separation of the subdivision from the noise source. Two typical applications of walls are to supplement the height of a berm which cannot be built taller because of structural or space considerations. The second application of a barrier wall is to shield a site for which control measures were not considered in early planning stages and, later, the land available to erect a berm is found to be inadequate. Typical acoustical barrier walls are shown in Figure V.2.B.13.

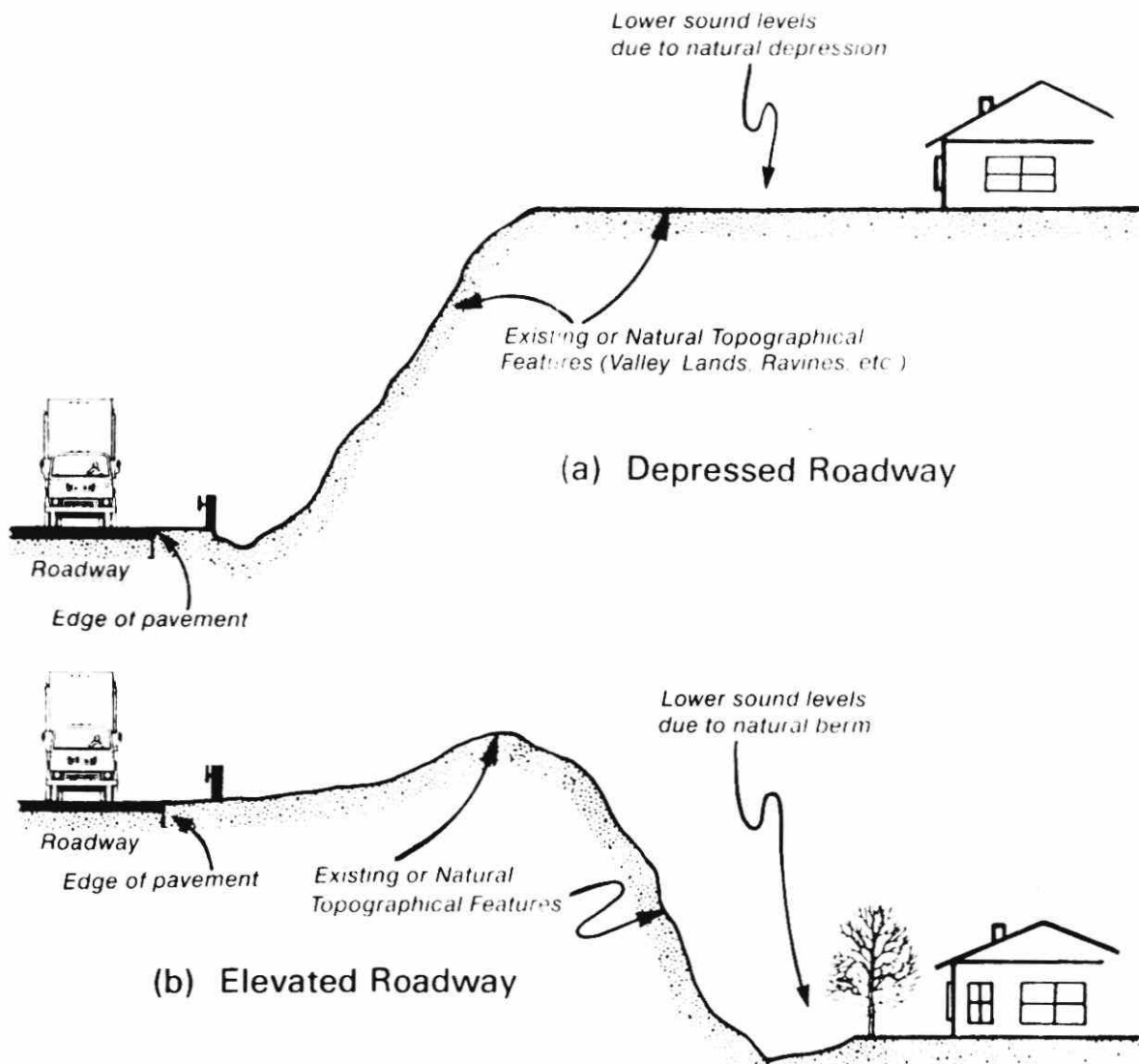


Figure V.2.B.10.: Lower Sound Levels Created by Existing or Natural Topographical Features (reductions up to 20 dBA are possible)

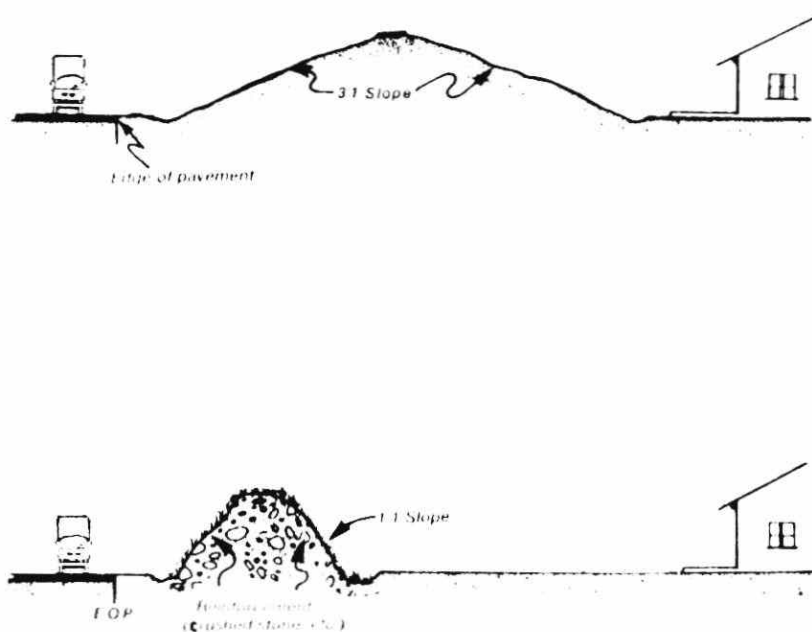


Figure V.2.B.11.: Typical Profiles of Specially Designed Berms

Acoustical barrier walls can be employed early, as well as late, during the planning process to control outdoor levels. To be effective the walls must be free of gaps and holes. Concrete walls are commonly used in most applications followed by brick walls, timber and sheet metal fences. One major disadvantage of barrier walls is that they are aesthetically less acceptable than berms. Structural and stability considerations are especially critical in the design of high walls (higher than 10 feet).

V.2.B.5.4. Intervening Structures as Barriers

In this method buildings located in the first row perform the function of the noise barrier for the rest of the site. The buildings so utilized are called barrier blocks.

Before we discuss barrier blocks for noise control we should differentiate clearly between this method and the method of orienting the outdoor recreational areas, the two methods are often confused with each other. By orienting the outdoor recreational area, the planner aims at providing quieter recreational areas for individual units or blocks. This is accomplished by rearranging these units or blocks themselves. By using an intervening structure as a barrier, the aim is to provide quieter outdoor areas not just for the residences in the first row, but for the entire site. As an illustration, shielding the backyard of a barrier block itself is considered as an exercise in the orientation of the recreational area, while the barrier block is considered as an intervening structure to shield the rest of the site.

Among the four noise control measures discussed under the heading of acoustical barriers, barrier blocks apply most widely, and offer the most creative and elegant answer to the subdivision noise-impact problem. Some basic features of a barrier block are listed below.

- (i) It is a very economical measure, since the structure in the first row performs dual functions, one as the barrier to shield the site from noise, and the other to house residential, commercial or other types of activity.



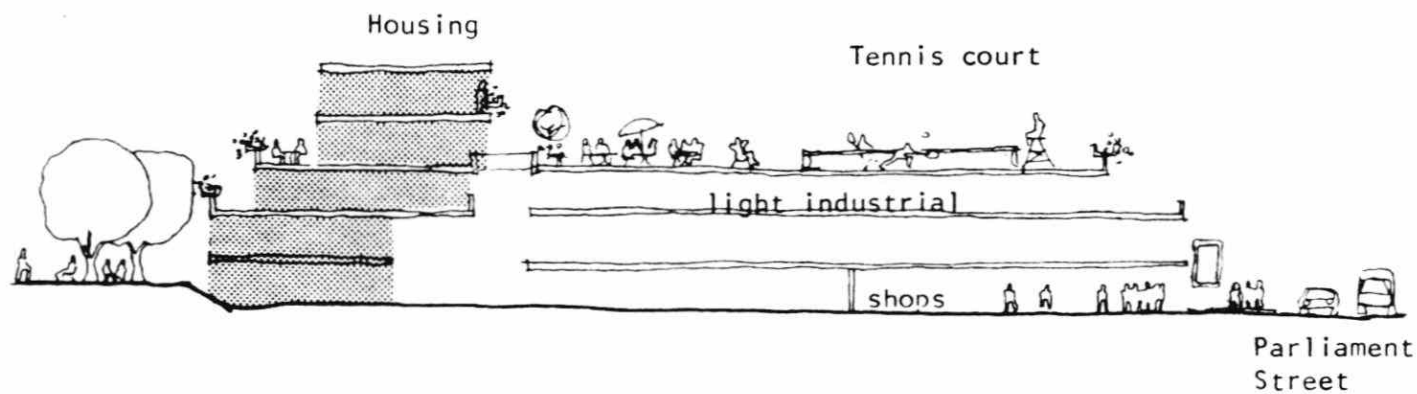
- (ii) Since the planner has the choice to decide how the first row is to be utilized before it is actually built, this method offers high flexibility and provides an opportunity to ensure compatible land use and introduces interesting site diversity.
- (iii) To be effective, barrier blocks should be continuous and placed as close as possible to the noise source or the noise sensitive area. Thus, for a site directly exposed to the noise source, the barrier block should ideally abut the noise source. The passageways or gaps between the blocks to provide access or to fulfill fire control regulations must be minimized. Care must be taken to adequately protect the end blocks which normally have larger exposed wall areas than the inside blocks.
- (iv) The barrier blocks are generally designed to be taller than the dwellings to be protected.

The widespread acceptance and use of the barrier blocks by planners and developers has resulted in many different configurations and variations being developed. Some of these arrangements are reproduced in Figure V.2.B.14. from the St. Lawrence Housing Study. Figures V.2.B.15. to V.2.B.19. show commercial, industrial and medium density residential buildings (townhouses) arranged in different ways along the periphery of a residential subdivision to act as a barrier block for the entire site. Reductions in the range of 10 to 17 dBA have been obtained.

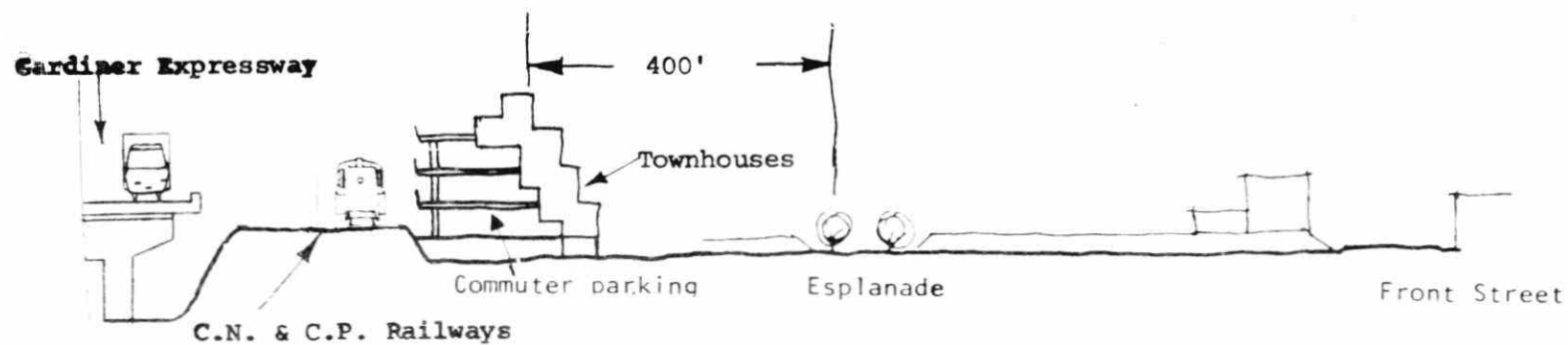
The use of barrier blocks to solve noise problems is quite widespread and effective. The Noise Pollution Control Section highly recommends the use of barrier blocks to achieve economical and aesthetically acceptable outdoor noise control at the subdivision site. The planning for barrier blocks must begin early in the subdivision design process.



(a) Barrier Block as Office Space



(b) Barrier Block as Tennis Courts, Light Industry and Shops



(c) Barrier Block as Multi-Story Car Park for Residents

Figure V.2.B.14. Some Applications of Barrier Blocks Recommended in the St. Lawrence Housing Project

V.2.B.6 ARCHITECTURAL DESIGN AS NOISE CONTROL MEASURE

The noise control measures discussed in this category are created and deeply influenced by the architectural design of the residential building. These measures are mostly employed to meet indoor noise level limits, although applications to reduce outdoor levels are also illustrated later. The four different types of architectural designs are discussed below.

V.2.B.6.1. Orientation of Balconies and Terraces

The concept used here is the same as discussed under the topic of orienting the outdoor recreational area in the Section V.2.B.4. with one difference. The earlier discussion applies to the recreational areas located on the ground level (such as backyards, patios etc.), whereas this discussion concentrates on the outdoor recreational areas located at higher elevations. Examples of such areas are balconies, and terraces of the high and medium rise apartment buildings and stack townhouses which are more closely integrated with the architectural design of the residences than those discussed previously.

As with the backyards and the patios in the earlier case, the balconies are planned on the shielded side of the building. This solution, however, can only be applied to one side of a dual-aspect or double-loaded building because of the excessive noise exposure on the other side. Figure V.2.B.20. shows a typical application for the St. Lawrence Project, in which the balconies are proposed on the quieter side of the apartment building.

Shielding of the outdoor area by locating it in the acoustical shadow of the building to reduce levels is an inexpensive measure easily adopted during the early planning stages.

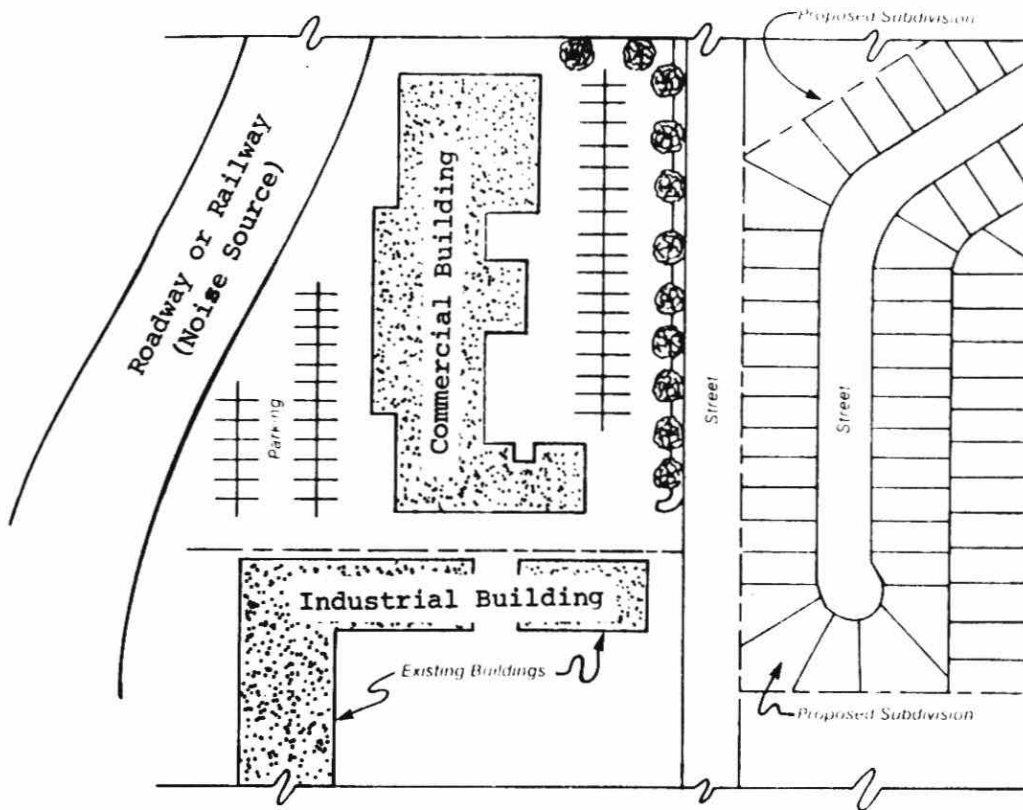


Figure V.2.B.15(a): Commercial and Industrial Buildings as Intervening Structures

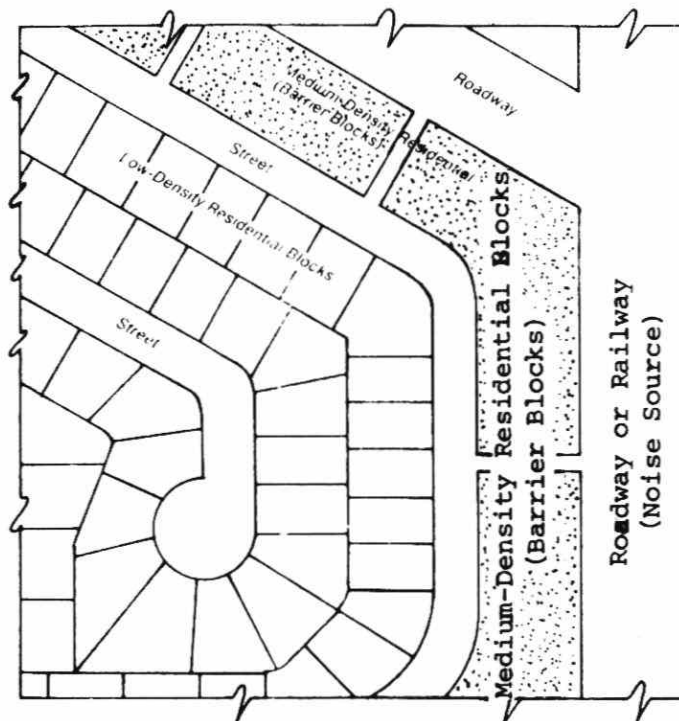


Figure V.2.B.15(b): Typical Mixed Residential Blocks as an Intervening Structure

V.2.B.6.2. Room and Corridor Arrangements

Indoor noise levels in the noise sensitive areas of the home can be substantially lowered by arranging the less-sensitive rooms and spaces adjacent to the exposed walls. The noise-sensitive areas include bedrooms, living rooms and dens where sleep, speech communication and relaxation activities take place. By comparison, kitchen and bathrooms are considered to be less noise-sensitive applications. Examples of uses which are not at all sensitive to noise are closets, storage rooms, corridors, stairways, etc. Figures V.2.B.21. and V.2.B.22. show two floor plans of detached homes designed specifically to reduce the indoor noise impact on residents. Also to be noted are the locations of the corridor, garage and kitchen in Figure V.2.A.21. which are adjacent to the noise exposed walls.

With the use of good planning principles applied in the early stages of the floor-plan design, the problem of noise exposure of the occupants of the home can be effectively solved at practically no added cost.

V.2.B.6.3. Orientation of Windows

Indoor noise levels can be lowered by providing the windows on the walls which are not directly exposed to the noise source. In the house plans of Figures V.2.B.21 and V.2.B.22. the windows of the bedrooms and the living room are arranged in the walls facing the garden and not the arterial.

The effectiveness of this measure depends on the orientation of the wall with respect to the noise source. If the wall with the windows in it is parallel to the noise source on the shielded side of the house, significant reduction of indoor levels can be realized. For windows designed in the walls running perpendicular to the noise sources, the reduction is expected to be slight.

There is no added cost involved in orienting the windows on the unexposed walls. This measure is quite effective in controlling indoor levels and can be considered early as well as late during the planning process.

Consideration should also be given to the orientation of windows with respect to exposure to sunlight.

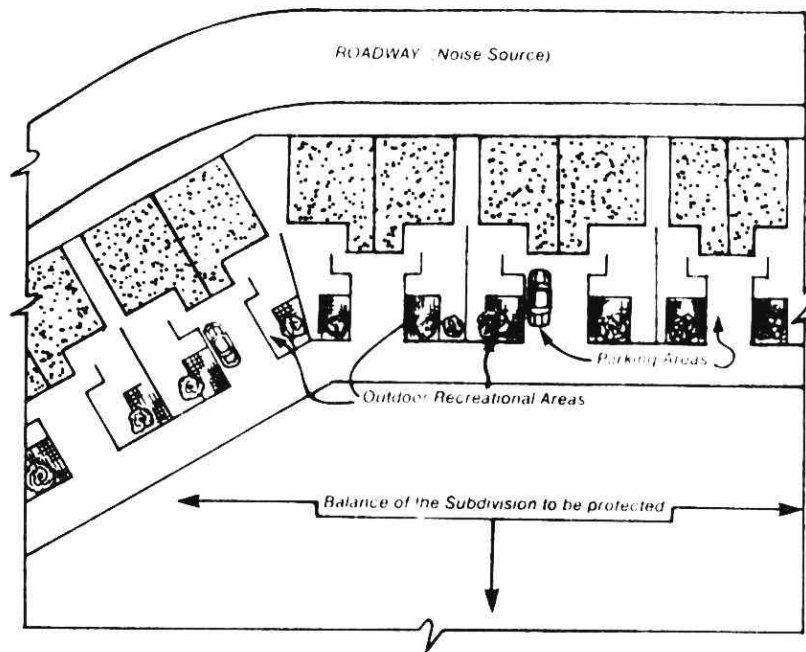


Figure V.2.B.16.: Turned in Ends of Barrier Blocks

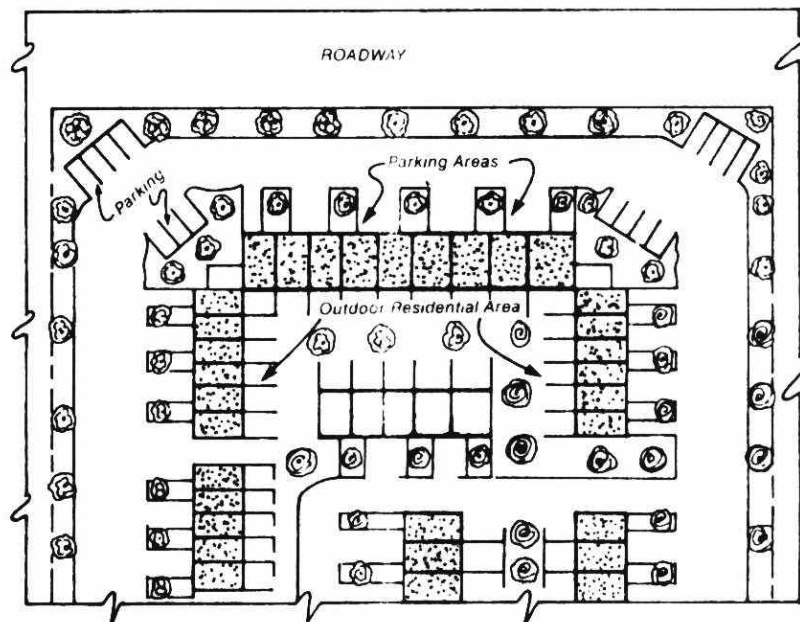


Figure V.2.B.17.: U-Shaped Barrier Blocks

V.2.B.6.4. Blank Walls

From the noise insulation viewpoint, the window is the weaker link of a wall-window combination. For dwellings exposed to very high noise levels the exposed walls should be windowless. This is done by relocating the windows to other walls subjected to lower noise levels. The blank walls find application in the high density housing (high rise apartments), stack townhouses and also for the low and medium density housing (detached homes, townhouses, rowhouses etc). An example of the former is illustrated in Figure V.2.B.23. where the apartment building wall facing the busy roadway is the blank wall and the windows are provided on the shielded side only. An example of indoor noise control by providing a blank wall for a townhouse is shown in Figure V.2.B.24. Similarly, the wall facing the arterial in Figures V.2.B.21. and V.2.B.22. are for the most part blank walls.

The use of blank walls imposes two restrictions. The conventional house plan normally relies on operable windows located in opposite walls to provide adequate lighting and ventilation. With the use of one blank wall the flexibility to provide windows is somewhat reduced and care must be taken to ensure sufficient lighting and ventilation. One such alternative is to design units to be slightly wider than normal. The other restriction is that apartment buildings with one blank wall are "one side" loaded, resulting in the corridors, and passage-ways being under-utilized.

The application of blank walls should only be confined to the extreme cases where the noise problem is too serious to be resolved by other measures. The likelihood of poor lighting and ventilation dictates that this measure be used with the utmost discretion and only as a last resort.

Significant reduction of noise levels indoors is possible with the use of blank walls. The measure can be used early as well as late during the subdivision planning process. The cost of this measure may, in fact, range anywhere between slightly lower to somewhat higher than the cost of a wall window combination.

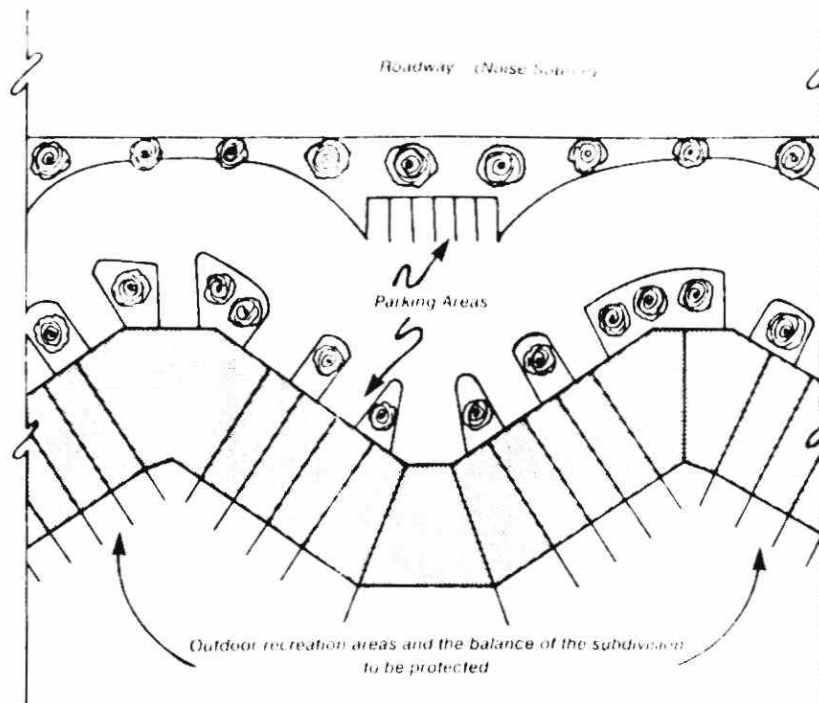


Figure V.2.B.18.:Zig-Zag Shaped Barrier Block

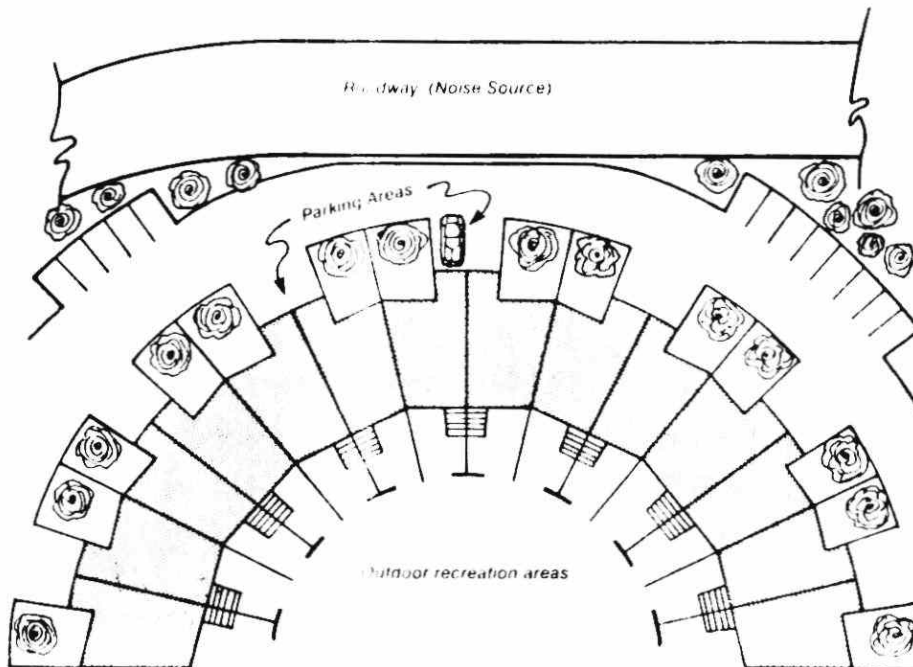


Figure V.2.B.19.:Fan Shaped Barrier Block

V.2.B.7. CONSTRUCTION TECHNIQUES AS NOISE CONTROL MEASURES:

If indoor noise levels cannot be lowered sufficiently by the design of the architectural features, further reduction is possible by employing special construction materials and techniques. To minimize the cost of noise control these measures should only be considered after the various architectural features favourable to the noise reduction have been fully explored. The specific measures are discussed below.

Acoustical Treatment of Walls, Windows, Doors and Roofs: If the orientation of windows, rooms and corridors together with the application of blank walls cannot provide compliance with the indoor noise level limits, the selection of special construction material is considered as a next step. A description of the various acoustical treatments is beyond the scope of this topic. We simply intend to establish here that the acoustical treatment of walls, windows, doors and ceilings is effective in reducing indoor noise levels (see Section V.2.D. for a fuller discussion on building materials).

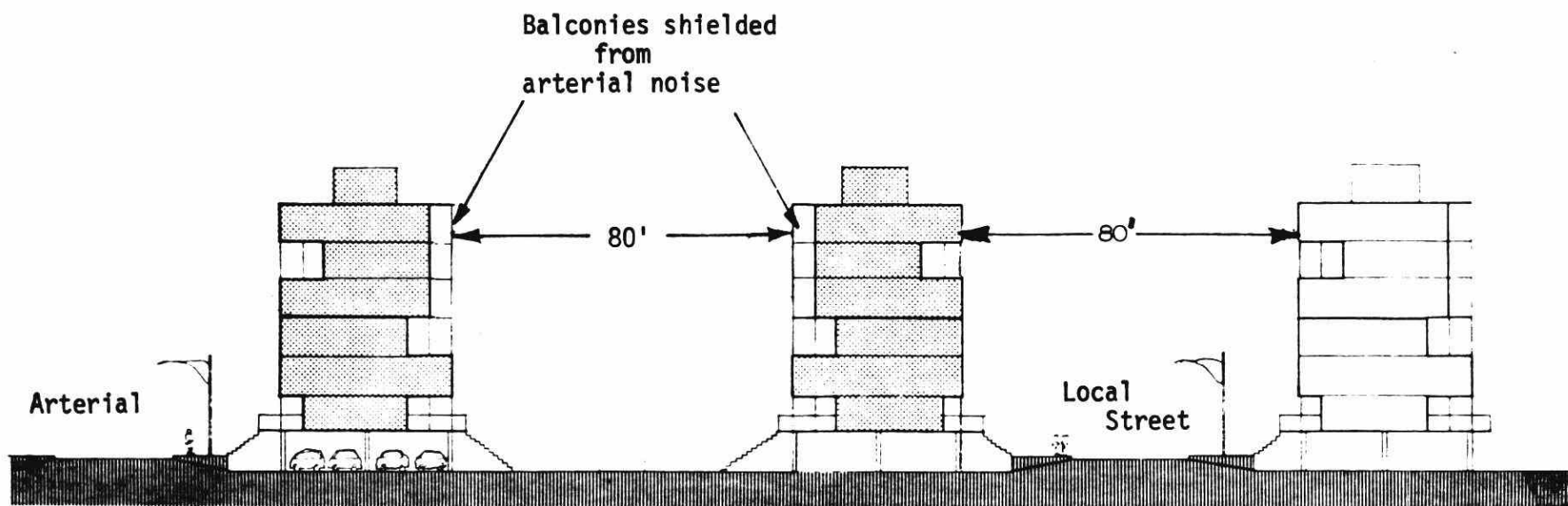
The acoustical treatment of walls involves the use of wider air spaces, added thickness of insulation material as well as the back up blocks. The acoustical treatment of the windows includes:

- (i) the sealing of the standard windows in the wall;
- (ii) reducing the size of windows;
- (iii) increasing the glass thickness;
- (iv) using double glazed window with air-gap between the panes (ventilation of air-gap to prevent moisture lock also to be considered).

The acoustical treatment of the doors involves one or more of the following steps:

- (i) providing a solid core door;
- (ii) adding a screen door;
- (iii) providing double doors

The conventional construction techniques and the materials used in roofs and ceilings usually provide adequate sound insulation. Special acoustical treatment of roofs is generally considered only for buildings exposed to aircraft flyover noise.



Reproduced from the Report of the St. Lawrence Housing Project, City of Toronto Housing Department

Figure V.2.B.20. Orientation of Balconies to Provide Shielding from Noise

Measures requiring special acoustical treatments add to the cost of the dwellings and should only be considered if other economical solutions are not effective to meet the indoor levels.

Air Conditioning and Ventilation: The use of blank walls and sealed windows as the noise control measures could create insufficient ventilation problems. This problem can be solved by forced air ventilation or air conditioning or ventilation through openable windows on the quiet side of the building.

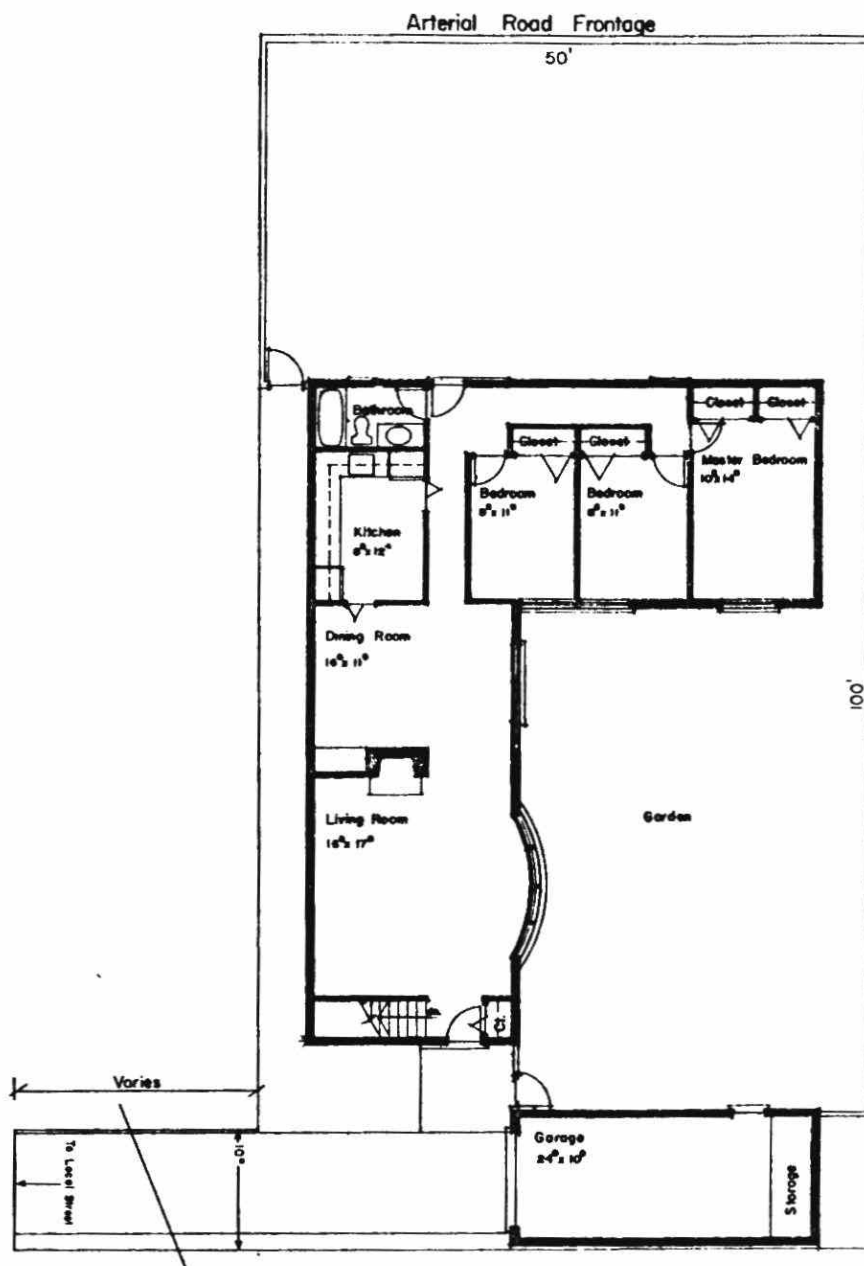
To provide air conditioning is a relatively expensive measure and should only be considered if the ventilation problem cannot be solved by other methods. Further, it is not encouraged for reason of energy conservation. This measure can be considered early as well as late during the planning process.

V.2.B.8. CHECK LIST OF NOISE CONTROL MEASURE:

So far we have discussed the various noise control methods for new housing, their recommended timing through the subdivision planning process, the cost factors, and their advantages and disadvantages. In Table V.2.B.3. we will summarize the considerations in the form of a check list for the use of the planners and architects. Although the check list is developed on a systematic and methodical basis, it can at best be offered only as a rational approach to solve the problem. The considerations unique to each subdivision development make it impossible for the check list to apply to the wide range of possibilities. Good judgement, common sense and discretion must be used when applying this check list.

V.2.B.9. CASE HISTORIES OF INTEGRATING NOISE CONTROL MEASURES IN THE SITE PLAN

The following cases, some of which are extracted from the files of the Noise Pollution Control Section, illustrate how the noise control measures can be incorporated into new housing plants. This does not necessarily constitute an endorsement of the approach by the Noise Pollution Control Section, but simply demonstrates the practicability of the various measures and their potential applications by the planners and architects in actual cases.



Note: The wall directly exposed to the arterial is used for noise-insensitive uses of bathroom, hallway and closets. Also, the windows open to the shielded garden.
 Reproduced from the Key Lot Study prepared for the Townsend Community Development Program.

Figure V.2.B.21.: A Proposed Floor Plan for the Townsend Program Specially Designed to Reduce Noise Impact

V.2.B.9.1. St. Lawrence Housing Project, Toronto

The St. Lawrence Housing Project will house 10,000 people of all ages and income in an area near the Toronto Waterfront which, at present, is severely impacted by noise from the elevated Gardiner Expressway and the train activity of the main C.N. and C.P. rail lines. The proposal calls for rowhouses and garages integrated with the berms and walls as intervening structures which are arranged so as to be almost continuous (Figure V.2.B.25.). The purpose of this arrangement is to protect the houses located inside the core area from noise. It should be noted that erection of a continuous berm could also provide the same noise attenuation but not offering nearly so diverse, interesting and aesthetically acceptable a site plan, as the use of the various techniques do. A newspaper clipping is also reproduced here on this same development.

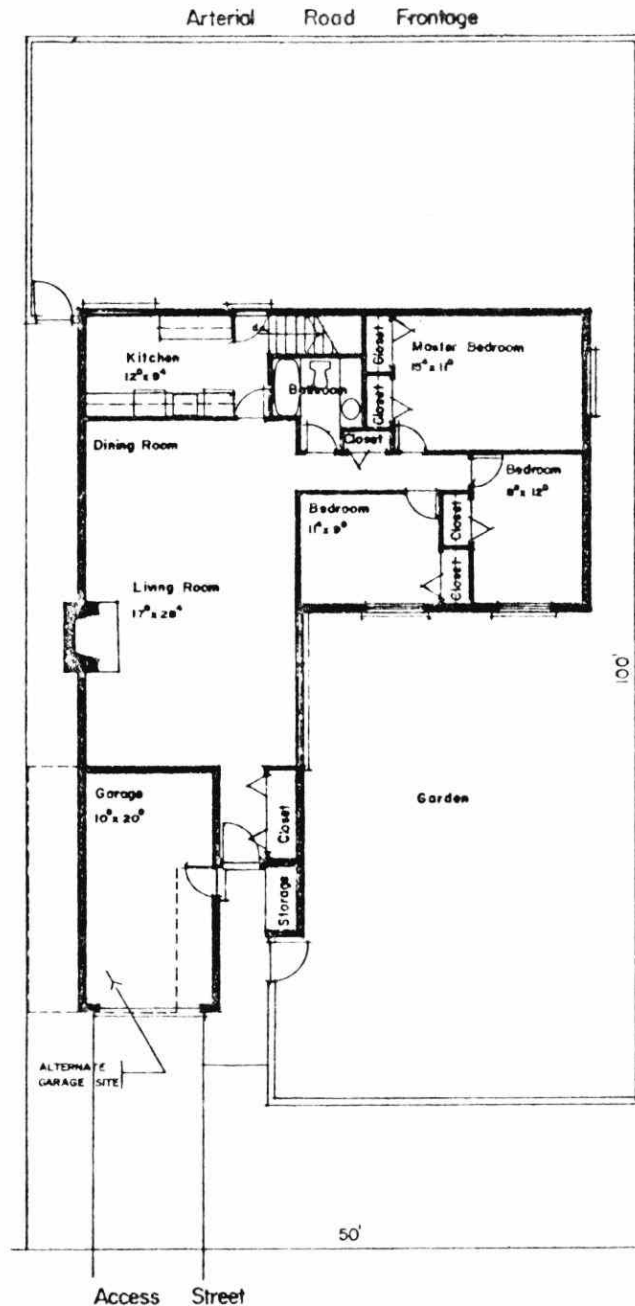
V.2.B.9.2. Apartment Building in the London Borough of Camden, U.K.

This following case illustrates that effective noise control can be designed even for the most hostile noise environment.

The use of glazed windows, blank walls designed of special constructional material and shielded recreational areas is illustrated in this application.

V.2.B.9.3. Townhouse Development Exposed to Train Noise

This is a case history from the files of the Noise Pollution Control Section. Townhouses were planned for a subdivision located on Harris Avenue, in a location exposed to train noise. Initially, the site plan was prepared without due consideration to the noise control measures, as shown in Figures V.2.B.26. Outdoor noise levels could not be complied with over the most part of the subdivision. The 10 ft. and 20 ft. buffer zones were virtually ineffective in providing any noise reduction. In Figure V.2.B.27., the buffer zones were eliminated, and the townhouses were arranged in the form of a long and near continuous barrier block, running parallel to the train tracks. As a result the recreational areas for the entire subdivision were substantially shielded against train noise. It should be noted that the land yield has remained unchanged at 116 units after rearrangement, and, in fact, the noise problem was solved without incurring any additional cost.



NOTE: The noise-insensitive uses such as kitchen, stairs and closets arranged adjacent to the wall exposed to the arterial noise. To reduce indoor noise levels, windows are designed to face away from the arterial.
 Reproduced from the Key Lot Study prepared for the Townsend Community Development Program.

Figure V.2.B.22. An Alternative Proposal of a Floor Plan Specially Designed to Reduce Noise Impact

Measure	Application		Possible		Recommended		Remarks	
	Control Indoor Levels	Control Outdoor Levels	Timing of Application in Subdivision Planning Process		Timing of Application in Subdivision Planning Process		Cost Considerations	Advantages/Limitations
			Early	Late	Early	Late		
SITE PLANNING								
1. Distance Set-back		✓	✓		✓		High	impractical for urban areas
2. Noise Sensitive Buffer Zones		✓	✓		✓		Slight to moderate	Moderately effective, wide range of possible application
3. Orientation of Outdoor Recreational Areas (located on ground levels)		✓	✓		✓		Very little or no cost	Quite effective, highly recommended
ACOUSTICAL BARRIERS								
1. Favourable topographical Features as Barriers		✓	✓		✓		Little or no cost	Quite effective
2. Earth Berms		✓	✓	(sometimes) ✓	✓		moderate to high	Problems with visibility, maintenance, snow removal etc. Should be considered if spare earth is available at the site, aesthetically less acceptable
3. Barrier Walls and Fences		✓	✓	✓	✓	✓	High	Maintenance and visibility problem. Cuts down on Head-light glare, provides excellent and sharp physical separation
4. Intervening Structures as Barriers		✓	✓		✓		Very little or no cost	Very effective, highly recommended
ARCHITECTURAL DESIGN								
1. Blank Walls	✓		✓	✓	✓	✓	little or no cost	Places severe restrictions on conventional designs and can pose problems in providing adequate lighting and ventilation
2. Room and Corridor Arrangement	✓		✓	✓(sometimes)	✓	✓	little or no cost	very effective for high noise level exposures
3. Placement of Balconies and Terraces (located at higher elevations)		✓	✓		✓		little or no cost	very effective, highly recommended
4. Orientation of Windows	✓		✓	✓(sometimes)	✓		little or no cost	very effective, highly recommended
CONSTRUCTION TECHNIQUES								
1. Special Acoustical Treatment	✓		✓	✓	✓	✓	moderate to high cost	effective
2. Air Conditioning and Ventilation	✓		✓	✓	✓	✓	high cost	should be used as a last resort, discouraged due to energy conservation considerations

NOTE:

1. The sequence in which the noise measures should generally be considered is, site planning, acoustical barriers (natural topographical features and intervening structures), architectural design and, construction techniques, and acoustical barriers (earth berms and walls).
2. It is usually possible to meet indoor and outdoor noise level limits by little or no added cost, if noise impact is considered very early in the planning process.
3. This check-list attempts to rationalize the approach to the noise control problem. It is not claimed to be authoritative nor exhaustive, but merely offered here as a suggestion.
4. The qualitative cost considerations provided here enable a comparison to be made between the cost of two or more alternative measures.
5. The principles of noise control as applied to land use planning are relevant to the preparation of Official Plans as well as to the planning of subdivisions.

Table V.2.B.3.: Check-list of the Noise Control Measures for New Housing

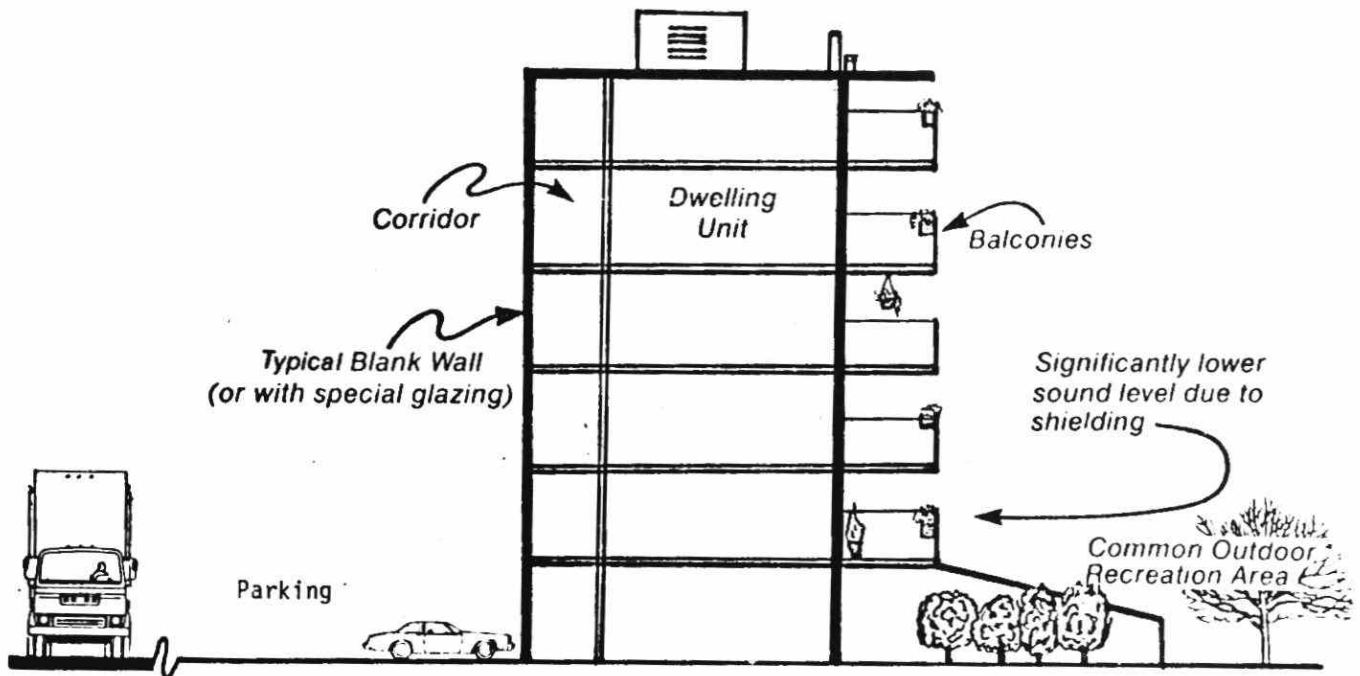


Figure V.2.B.23.: The Use of Blank Walls for an Apartment Building or Stacked Townhouse

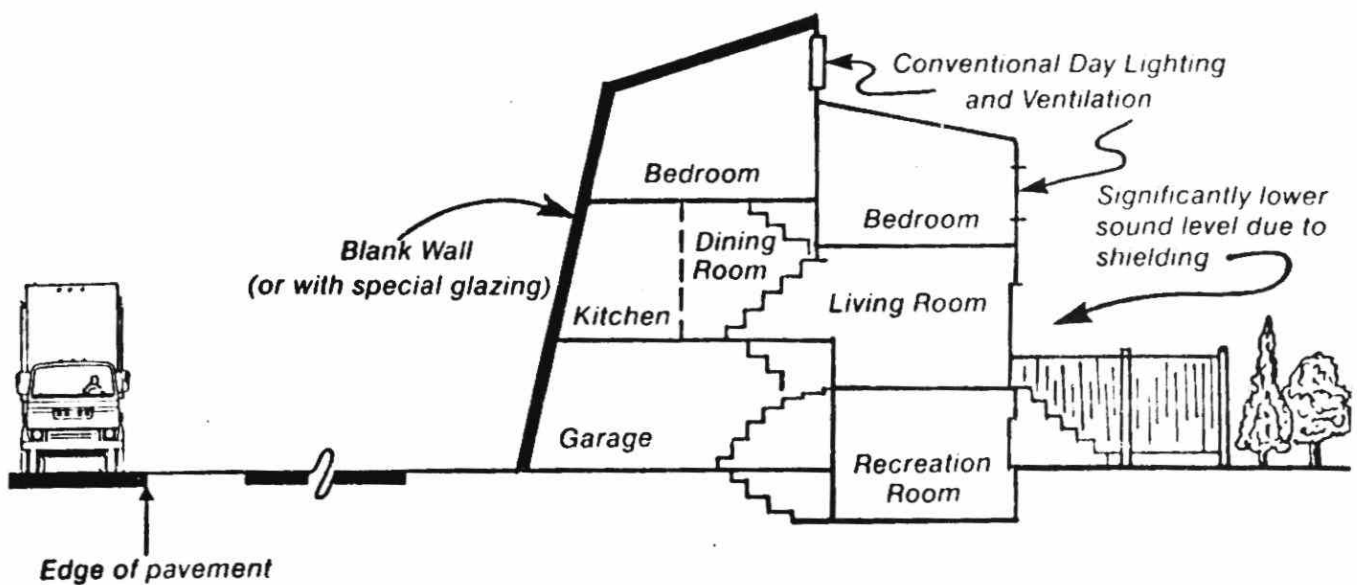


Figure V.2.B.24.: The Use of Blank Walls for a Townhouse

A new way to live away from all the noise and dirt

By JANICE DINEEN
Star staff writer

It's not the obvious location for the home of your dreams.

On the contrary, it is an ugly sight, a dreary accumulation of scrap yards, parking lots and old warehouses beside an expressway and some railway tracks.

But when Frank Lewinberg stood at Parliament and Esplanade Streets looking west late in 1973, somehow he saw the houses, shops and schools that now are about to go up.

"I just had a sense that there was nothing happening there—it was a waste of land when it could be a great place to live," recalls Lewinberg, then a city planner in the King-Parliament area and now a researcher for the NDP.

All ages

The shovels are expected to go into the ground next spring on the site Lewinberg discovered, now known as the city's St. Lawrence development.

Planners are working on the premise that a kind of model neighborhood can spring up a few blocks from downtown Yonge Street, housing 10,000 people of all ages and incomes.

But model neighborhoods aren't usually known for noise, fumes and vibrations from nearby highways and trains, or dust and pollution from parking lots and scrap yards.

There are 200 trains a day rattling and roaring past the St. Lawrence site, and more coming in the future, according to Bryan Corson, superin-



ALAN LITTLEWOOD

"I nearly choked"

tendent of the Toronto Terminal's Railway Company.

"We are not objecting to the development, but we are concerned about the safety of people trespassing on railway property, and about the hazards of noise, vibrations and fumes," Corson said in an interview. He said several freight trains go by the site every day with diesel locomotives spewing clouds of oily exhaust.

This comes as no surprise to city planner Alan Littlewood, who is working on plans for the development. Last week Littlewood was

standing on the site when a diesel locomotive went by.

"Suddenly I was covered in a brown cloud," he said ruefully. "I nearly choked to death."

Littlewood and the other city planners involved in St. Lawrence have made pollution threats to the site a major focus for their attention. In the last two years, the city has spent \$200,000 for environmental studies on what problems exist and how they can be overcome.

The planners also have kept in close contact with the provincial Ministry of the Environment for advice and approval in planning the development to block out pollution.

Tainted soil

Some pollution problems were easier to deal with than others.

When the planners hired an engineering firm to conduct studies on how vibrations from the railway will affect St. Lawrence houses, the studies showed that the vibrations are imperceptible to people, and very slight on recording equipment.

Tests of soil around the site showed up high levels of lead and cadmium contamination in several areas, deposited by industry operating there and cars in the parking lots.

"We'll strip the soil, remove it and dump it," said Littlewood. "It's the only really safe thing to do."

Air pollution proved to be a little trickier. Provincial monitors found that the air quality around St. Lawrence was far from ideal, but was no worse than the rest of the downtown area. They concluded: "While we would like to see air pollution condi-



—Star photo by Doug Griffin

DOWNTOWN noise and pollution will be combated with sound barriers and other measures in St. Lawrence housing project. The city is

building parkland and housing for 10,000 people between Front Street and the Gardiner Expressway from the O'Keefe Centre to Parliament Street.

tions improve in Toronto in general, there is no special problem in regard to this site that would make it unsuitable for residential use."

The high dust levels around St. Lawrence are the result of the industries operating there now. When they go the planners calculate, the dust problem will go with them.

The most challenging pollution problems came with noise and fumes from traffic and trains.

"This isn't simple; it's a very complex problem," Littlewood acknowledged. "It will be difficult to

make this affordable, decent housing, but it can be done."

Studies and tests showed, surprisingly, that the worst noise problems came from traffic on Jarvis, Front, Parliament and Sherbourne Streets. Next came the Gardiner Expressway. The railway came third.

All three will be dealt with in the same way, with a U-shaped protective shield of buffer buildings blocking the rest of the development from the noise and fumes.

The buffer buildings will be houses and apartments, designed so the heavy outside walls and double or triple glazed windows facing the noise sources will keep the levels of sound inside the U-shape to acceptable levels.

In the apartments along Jarvis Street, the corridors will face the road, and the apartment units will overlook the quiet side, away from the street. The houses along the railway and the other major streets will be designed on a similar theory.

Special care

"We take particular care with a buffer building," explained Paul Reuben of Irving Grossman Architects, the firm designing the first batch of buildings in St. Lawrence. "The side facing the railway and traffic noises will consist of bathrooms and kitchens that can be totally closed and soundproofed. The other side will have the living rooms and bedrooms and gardens."

Littlewood said the planners take comfort from the fact that houses only yards from a railway bridge near Davenport Road and Dupont Street sell for \$150,000. He said the design of the buffer areas in St. Lawrence is being done "in very close consultation with the Ministry of the Environment and our own noise consultants."

Aside from environmental questions, there have been few criti-

cisms or concerns raised about the St. Lawrence development.

However, John Brian of the Toronto Redevelopment Advisory Council is worried that there will be too many children in St. Lawrence.

"We believe that 1,000 children would be the maximum number for tolerable living conditions on that site," he said. "Adults can live together more amicably than when you have a lot of school-age children around."

"Generally we think this development is a positive step, but we think it could be pretty grim with too many children. If they design as many as half the units for families, you'll end up with a lousy project."

Littlewood said studies and conclusions differ on concentrations of children, what levels are ideal and what levels should be permissible.

"I can't tell you how many children per acre is the right number, and no one will know how many children will live in St. Lawrence until it is built," he said. "From the best calculations we can make now, we would expect about 1,750 children."

He said they are trying to provide adequately for them by designing the family housing in the development to resemble existing successful Toronto neighborhoods.

"We felt that families should live in three- or four-storey houses with back gardens, but we also wanted to see 30 to 40 per cent of the units designed for families. We did a study to see if that was possible, and we found it was. We can meet our targets and our criteria as well."

Littlewood said he feels a pleasant neighborhood can be created through the many other factors being planned, even with the up to 2,000 children the planners expect. One of these factors is keeping an income mix in the area by ensuring that no more than two-thirds of the housing units serve people who need

assisted housing. Another factor is the careful placing of parkland and stores around and among the houses and apartments. A seven-acre park runs through the middle of the development for its entire length.

"No one will be more than two minutes from the park, or a few minutes from the nearest retail stores," Littlewood said.

The circumstance that has amazed even the planners working on St. Lawrence is the speed with which the project is progressing.

"Everyone thought we were just another Metro Centre, and it would never really go ahead," Littlewood said with satisfaction. "Instead, in two years council has approved the official plan changes, the zoning bylaw is coming up this month, and we have hired architects."

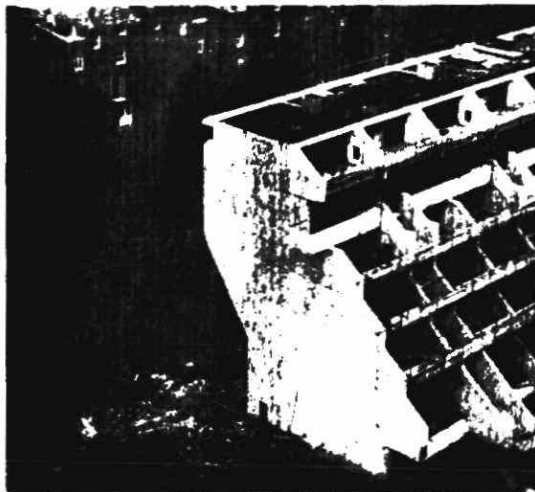
Move fast

"I think the whole thing is going to move very fast. We were originally talking in terms of 10 or 15 years, but now I wouldn't be surprised if the first two phases were built and in use before five years have passed."

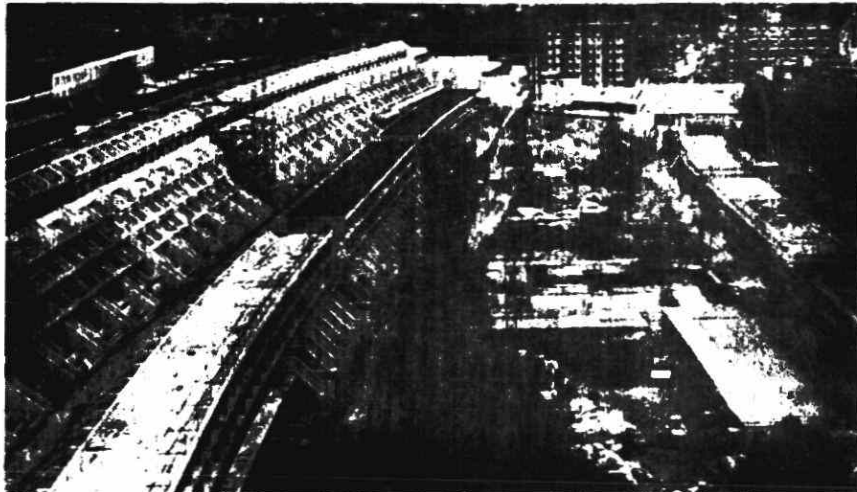
Other development activity in the area has encouraged the planners in their feeling that it's a fine location for new housing, shops and people-drawing development. A group is turning an old TTC storage building on the site into a theatre, and private developers have been assembling land for housing just outside the site.

It makes Littlewood and his co-workers take their job even more seriously.

"We don't want to be pushed by political expediency to create a development that is any less than it should be just to meet short-term goals," he said. "St. Lawrence will be there for 200 years. It is crucial that it be a high quality development."



Terraced building cantilevers over service road.



Acting as a barrier, six-story building protects the rest of development.

London housing floats on bridge bearings.

An apartment building under construction in London adjacent to a main railway line and a service road will float on bridge bearings to protect it from the vibrations of fast-moving trains. The building also has special design features to cut train noise levels from a maximum of 110 decibels to 60.

The 1,640-ft-long, six-story, terraced building hugs the contour of the track along its entire length at a constant distance of just 25 ft, acting as a noise barrier for the rest of a 12.5-acre, \$16.5-million residential development.

Also on the site are a second, parallel line of four-story, low-rise apartments, four-acre park, school, community center and underground garage.

The London borough of Camden was able to purchase the site at reduced cost because of the constant high noise and vibration levels.

Express trains pass the site at a rate of one every three minutes on their way in and out of a busy station on the main rail line linking London with the north of England, and railroad plans call for an eventual increase to 1,000 trains per day.

"Every time a train goes by, my whole body is shaken," says Peter Grootenhuys, professor of mechanical engineering at Imperial College, London, and a partner in the London-based acoustics and vibration consultant Grootenhuys, Allaway Associates.

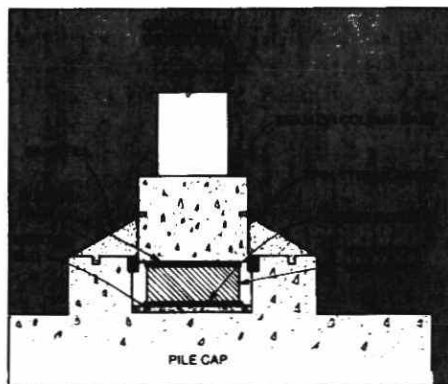
Noise levels of 110 decibels have been recorded at the site and readings of 95 to 100 occur frequently. "These are clearly intolerable levels—every bit as bad as Heathrow (London) Airport," says

Camden borough architect Neave Brown.

The terraced concrete building is cantilevered 15 ft out over a service road that, because of the severe demand for space, runs between the building and the railway tracks.

The terraced apartments rest on 12×12-in. precast concrete tie beams supported in troughs a few inches deep along the tops of pile caps. Protection against vibration is provided by shock-absorbing, composite steel-rubber bridge bearings under the tie beams and by rubber pads wedged into the trough along each side of the beams. The pads also prevent the beams from shifting laterally. The bearings are 4 in. thick unloaded. They compress less than 1 in. under the 270-ton load. The apartment cross walls are 19 ft long and are spaced 20 ft apart along the tie beams.

The apartments are supported by concrete piles, bored to depths as great as 60 ft in the London clay.



Shock absorbing bearing sits in pile cap.

As a fail-safe measure, the area around the pad is concreted to a level $\frac{1}{2}$ in. below the top of the pad so in case of failure, the beam will settle directly onto the concrete. To prevent solid material from entering the trough and transferring vibration to the beams, polyethylene sheeting was laid over the system and sand poured over it. "The bearings are designed to completely isolate the building from any vibration," says Grootenhuys.

The wall facing the tracks is 7.5 in. thick concrete blocks, with a 2-in. cavity, and is covered with a heavily textured cement mixture $\frac{3}{4}$ in. thick to help cut internal noise levels. All interior wall surfaces on the side of the rail line are lined with wall-to-wall and floor-to-ceiling closets backed by polystyrene, $\frac{1}{4}$ -in. thick. "These closets act as another cavity," says Brown, "and the clothes and other material also act as an insulator." Windows facing the tracks are double-glazed with a unusually large space between inner and outer panes. Sills, walls and ceiling areas between the glass are fiberboard acoustical tiling. While the maximum allowable internal noise in the apartments is 60 decibels, Brown feels that with this combination even lower levels will be achieved.

The balance of the structure is conventional, largely cast-in place concrete with some precast elements.

The low-rise of the complex closely matches the height of the Regency and Victorian-style housing that predominates in most of London's inner suburban areas.

Structural engineer for the job is Antony Hunt Associates.

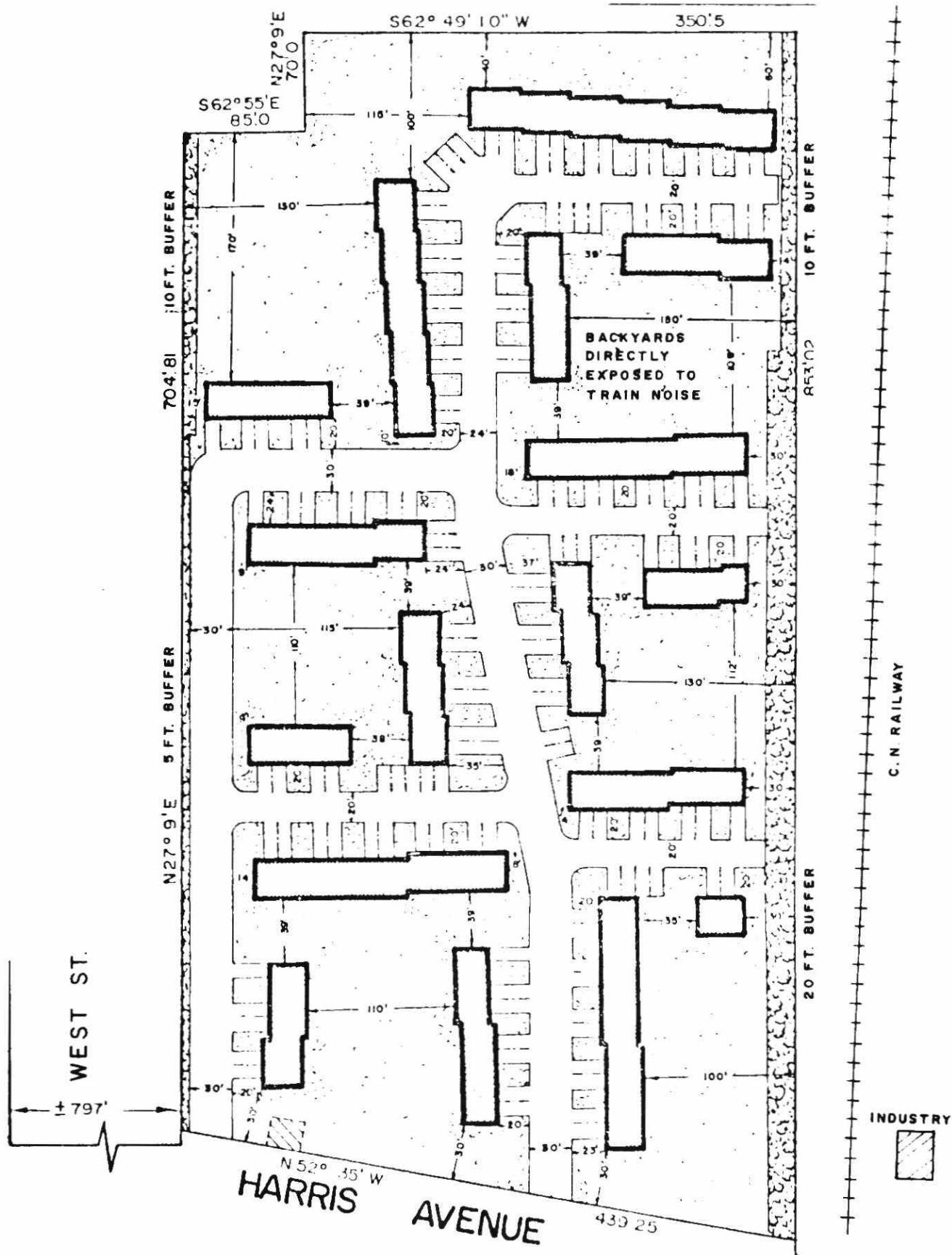


Figure V.2.B.26. INADEQUATE NOISE CONTROL MEASURES.

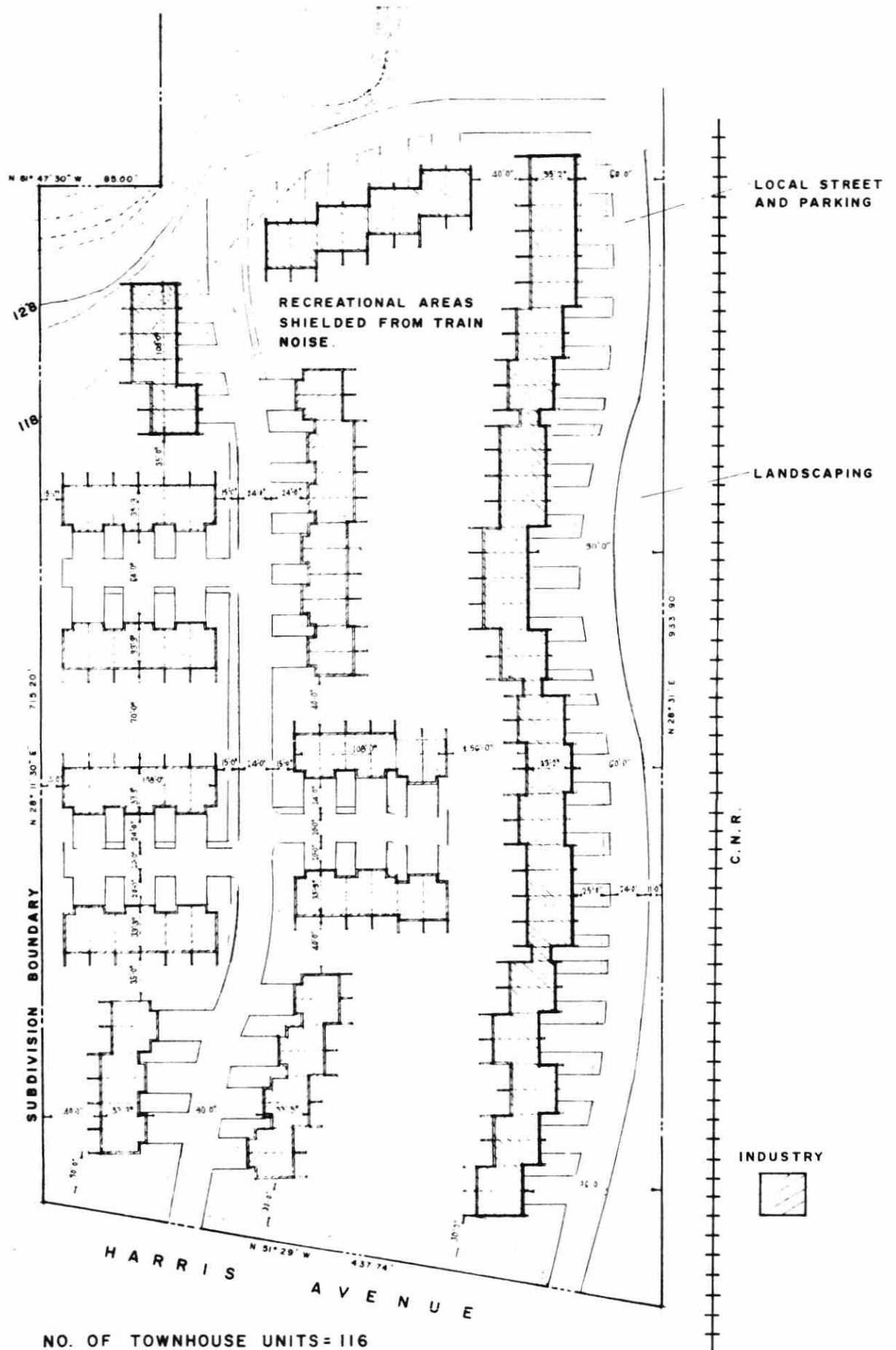


Figure V.2.B.27 NOISE CONTROL MEASURES INCORPORATED.

SUBJECT:
ACOUSTICS TECHNOLOGY IN
LAND USE PLANNING

TOPIC: V.2.C.
BARRIER CALCULATIONS

OBJECTIVES:

Trainee will be able to;

1. Realize the application of optical diffraction theory to sound attenuation by a barrier.
 2. Calculate path length difference (for thin and thick barriers) and Fresnel Number (N).
 3. Understand and use graphs of barrier attenuations for point and line sources.
 4. Discuss and use effective heights for various sources, realizing that introduction of a barrier reduces ground attenuation.
-

V.2.C.1. THE APPLICATION OF OPTICAL DIFFRACTION THEORY
TO SOUND ATTENUATION BY BARRIERS

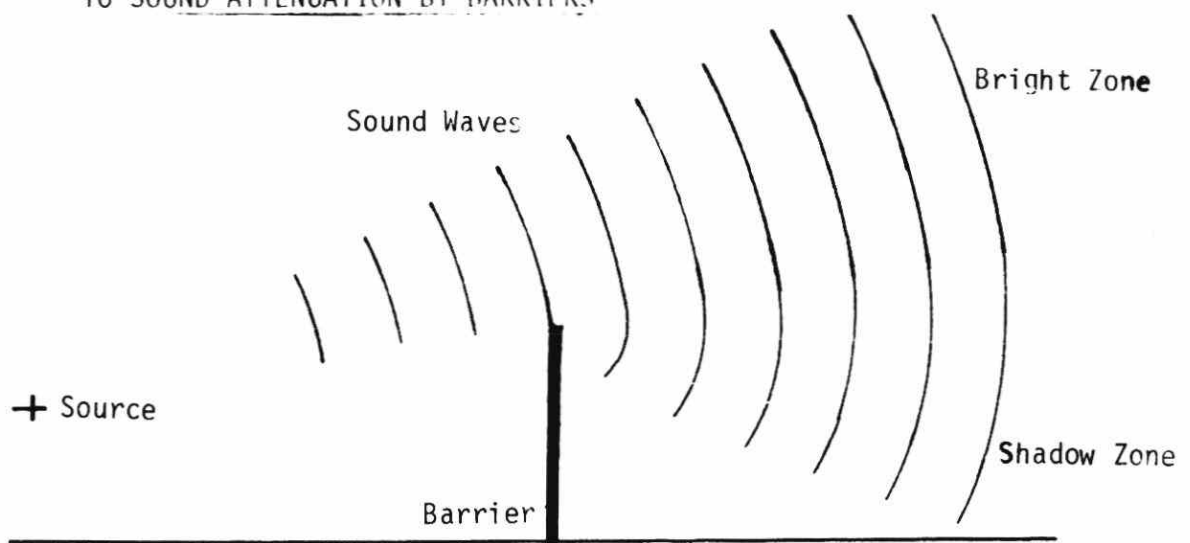


Fig. V.2.C.1. The Effect of a Barrier on Sound Waves

Fig. V.2.C.1. shows a progression of sound waves crossing a barrier (a wall, fence or similar construction). The sound waves near the top of the figure pass clearly over the barrier and are not affected by it. Sound waves which pass close to the barrier are "slowed down" by the barrier and hence bent round as shown in the Figure. The sound waves thus affected act as though the top of the barrier were an effective new source and commence to radiate spherically from the top of the barrier. As these sound waves radiate from the top of the barrier the sound pressure level must decrease in comparison with those sound waves which pass well above the barrier. Thus, a receiver standing in the region of the bent sound waves will hear a lower sound level than a second receiver standing in the area of the unaffected sound waves.

This process of "slowing down" and hence bending the sound waves is closely similar to the process of diffraction in the study of the behaviour of light. Not only can optical diffraction theory be applied to the acoustical barrier situation, but the area of bent sound waves is described as the "shadow zone" and the areas of unaffected sound waves is described as the "bright zone". Both names follow the optical analogue applied to the acoustical case.

V.2.C.2. PATH LENGTH DIFFERENCE AND FRESNEL NUMBER

From optical diffraction theory, the sound attenuation of an acoustical barrier is found by calculating the "path length difference" or the extra distance the sound is forced to travel because of the presence of the barrier.

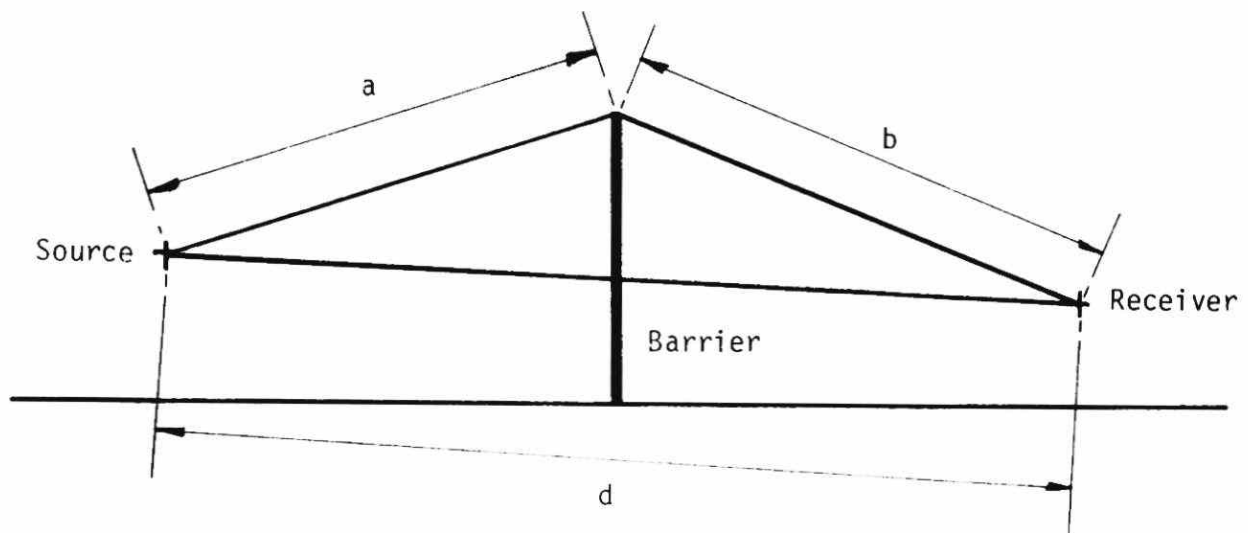


Fig. V.2.C.2. Definition of Path Length Difference

V.2.C.2.1. Thin Barriers

Figure V.2.C.2. shows a barrier placed between a source and a receiver. In the absence of the barrier, the sound travels directly between the source and the receiver, shown as the distance 'd'. However, with the barrier in place the sound must travel from the source to the top of the barrier (distance 'a') and from the top of the barrier to the receiver (distance 'b'). So with the barrier in place the sound must travel through a total distance of 'a + b'. Subtracting 'd' from 'a + b' gives the extra distance the sound must travel because of the barrier.

Thus Path Length Difference (PLD) = $a + b - d$
a, b and d can be easily calculated using Pythagoras' equation. Given the source barrier distance D_{SB} , the barrier receiver distance D_{BR} , the source height H_S , the barrier height H_B , and the receiver height H_R (see Figure V.2.C.3.) as follows:-

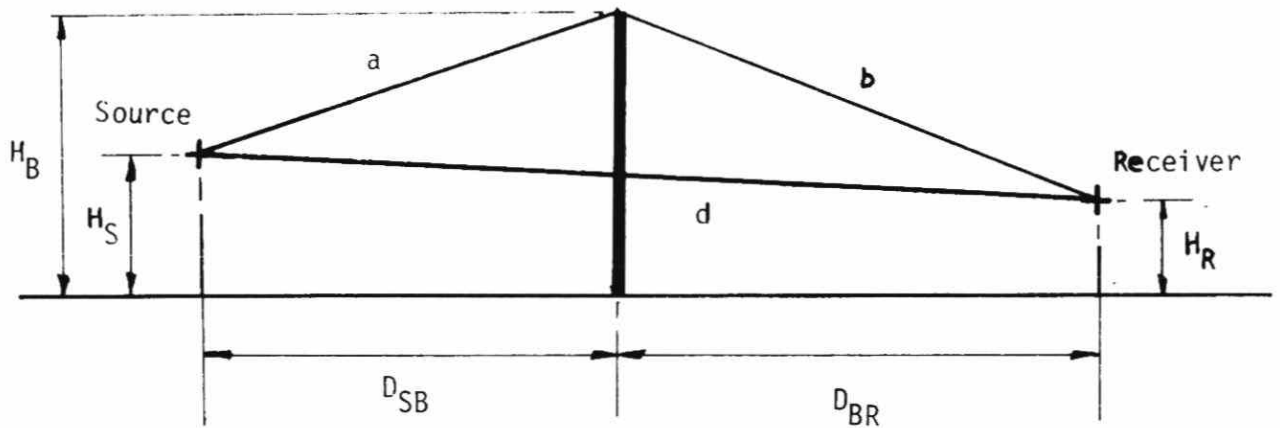


Figure V.2.C.3. Calculation of PLD for a Thin Barrier

$$a = \sqrt{(H_B - H_S)^2 + D_{SB}^2}$$

$$b = \sqrt{(H_B - H_R)^2 + D_{BR}^2}$$

$$d = \sqrt{(H_S - H_R)^2 + (D_{SB} + D_{BR})^2}$$

Which are used to obtained PLD thus:

$$PLD = a + b - d$$

.....(V.2.C.1.)

V.2.C.2.2. Thick Barriers

It is often possible to use a row of townhouses or even an apartment block as a noise barrier. In this case some extra sound reduction is achieved as the sound is diffracted around the two upper edges of the building. (see Figure V.3.C.4). Again the PLD can be used as a simple indicator of the sound reduction. If the building thickness is defined as T , then the calculation of PLD is as follows:-

$$a = \sqrt{(H_B - H_S)^2 + D_{SB}^2}$$

$$b = \sqrt{(H_B - H_R)^2 + (D_{BR} - T)^2}$$

$$d = \sqrt{(H_S - H_R)^2 + (D_{SB} + D_{BR})^2}$$

In this case:

$$PLD = a + b + T - d$$

.....(V.2.C.2.)

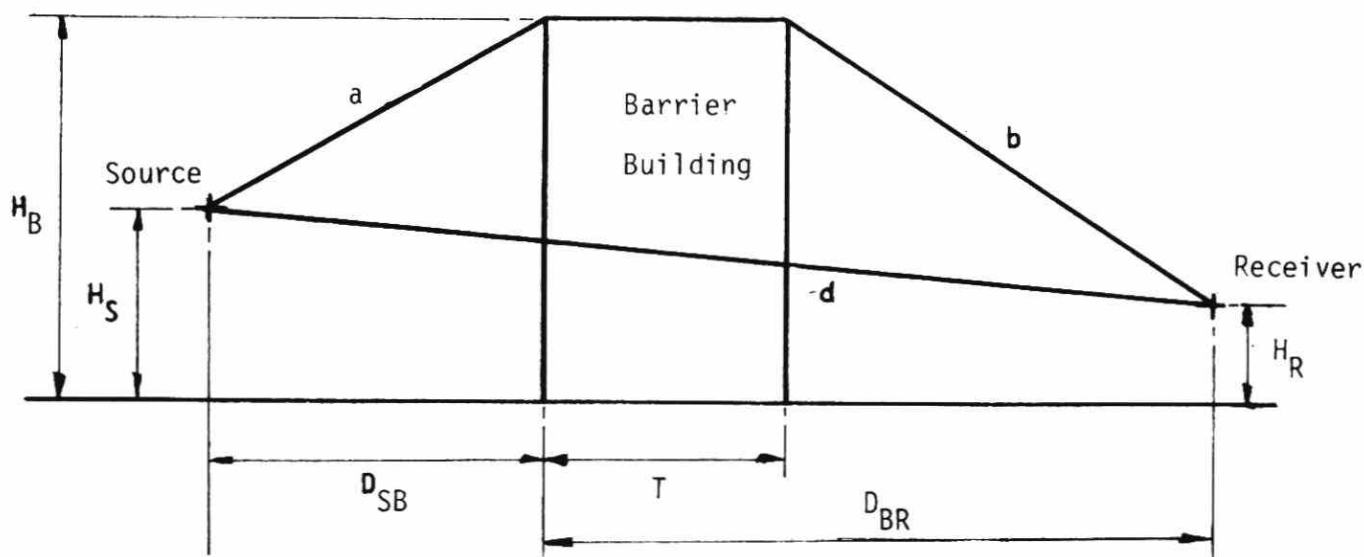


Figure V.2.C.4. Calculation of PLD for a Thick Barrier

Care should be taken when calculating PLD that the receiver is in the shadow zone, that is the source cannot be seen by the receiver. In this situation the PLD is given a positive sign and a significant sound attenuation will result. If however, the source can be seen by the receiver despite the presence of the barrier, then the receiver is in the bright zone and the PLD should be given a negative sign. In this latter case the barrier will give very little, or no, sound reduction at the receiver position

V.2.C.2.3. Fresnel Number

Once the PLD has been calculated, the sound attenuation of the barrier can only be calculated with a knowledge of the wavelength or frequency of the sound wave under consideration. This is necessary as low frequencies (or long wavelengths) can be diffracted or "bent" more easily than high frequencies (or short wavelengths). Following optical diffraction theory a "Fresnel Number" (N) must be calculated as follows before the sound attenuation can be found.

$$\text{Fresnel Number (N)} = \frac{2}{\lambda} \text{ PLD} \quad \text{.....(V.2.C.3.)}$$

where λ is the wavelength of the sound.

As we usually work with frequency rather than wavelength, it is useful to convert the formula for N into a form involving frequency (f) rather than wavelength.

$$\text{Now } f = \frac{c}{\lambda}$$

where 'c' is the speed of sound in air.

$$\text{Thus } \lambda = \frac{c}{f}$$

$$\text{and } N = \frac{2f}{c} \times \text{PLD} \quad \dots\dots(\text{V.2.C.4.})$$

Care should be taken when using this equation to use a consistent set of dimensions. If the PLD is calculated in metres, then the velocity of sound used must be in metres/second. If the PLD is calculated in feet, then the velocity of sound must be in feet/second.

$$\text{Thus } N = \frac{2f}{344} \cdot (\text{PLD in metres})$$

$$\text{or } N = \frac{2f}{1130} \cdot (\text{PLD in feet})$$

It is clear that in order to calculate the Fresnel Number (N) either the frequency of the sound must be known, or if the sound covers a wide frequency range then some representative frequency must be assumed. Typical frequencies used by the Ministry of the Environment are as follows:

→	Traffic:	500 Hz	
→	Locomotives:	250 Hz	
	Train Wheel/		
→	Rail Noise:	500 Hz	(see Topic V.2.A.2)

Knowledge of these frequencies allows calculation of simple conversion factors from PLD to Fresnel Number (N). Given in Table V.2.C.1. are the numbers by which the PLD should be multiplied to give the Fresnel Number for the three noise sources in the two sets of Units.

Noise Source	Multiply PLD by Factor to get N	
	PLD in Metres	PLD in Feet
Traffic	2.9	0.88
Locomotives	1.5	0.44
Train Wheel/Rail Noise	2.9	0.88

Table V.2.C.1 Multiplication Factors to Give Fresnel Number (N) from PLD

V.2.C.3. OBTAIN THE SOUND ATTENUATION FROM THE PLD
FOR POINT AND LINE SOURCES

It has been found that a barrier gives different values of sound attenuation for stationary point sources and line sources. Moving point sources - for which the attenuation in L_{eq} for a pass-by is required - should be considered as line sources. The attenuation for a line source is less than that for a point source. In Figure V.2.C.5, a graph is given for the barrier attenuation for both a point and line source.

The upper curve on Figure V.2.C.5 applies for a point source such as a stationary machine, car or truck, or an idling locomotive. The lower curve applies for a line source such as a continuous flow of traffic along a roadway or the wheel/rail noise from a long freight train. It can be seen from the graph that the attenuation provided by a barrier is less for line sources than point sources, making use of the correct curve important.

The formulae presented for this topic assume:

1. That the barrier is very long (at least eight times the source to receiver distance) or is turned through a right angle away from the source at both ends to protect the receiver from the sides, see Topic V.2.B.5.
2. That the barrier does not allow sound to penetrate through itself and thus raise sound levels in the shadow zone. To avoid this effect, the barrier can be made of any material (solid wood, masonry or earth in the form of a berm) so long as it has a density of 4 lbs/ft² and has no holes or gaps.
3. That the barrier is at right angles to a line drawn from the receiver to the source (for a point source) or a line drawn from the receiver perpendicular to the source (for a line source).

V.2.C.4. EFFECTIVE SOURCE HEIGHTS WITH REFERENCE TO
REDUCED GROUND ATTENUATION BY THE BARRIER

Before a barrier attenuation can be calculated the source height must be known. For a highly complex source such as traffic noise no single source height exists and so a single effective source height must be used. The choice of this effective source height may be affected by considerations of ground attenuation.

As a sound wave passes over a region of soft or grassy land, the source sound level decreases by more than the expected 3 dBA per doubling of distance for a line source, or the 6 dBA per doubling of distance for a point source. This extra sound level decrease is known as ground attenuation. If, however, the sound wave has to travel over a barrier in order to reach the receiver, it must necessarily travel further away from the ground and hence suffers a smaller ground attenuation.

The effect of interposing a barrier between a source and a receiver is thus two-fold. First, the sound level is increased because at least a part of the ground attenuation is removed and secondly, the sound level is decreased by the presence of the barrier and ensuing barrier sound attenuation. Thus, this removal of part of the ground attenuation makes the barrier less effective, a fact which must be taken into account when calculating the barrier attenuation. Two situations can arise, first, if the model used for predicting the noise level does not include ground attenuation or if actual measurements were made over hard ground then an actual source height can be used. Secondly, if the model used for predicting the noise level does include ground attenuation or if actual measurements were made over soft ground then a higher than actual effective source height should be used to reduce the calculated barrier attenuation.

In this course, two prediction models in use by the Noise Pollution Control Section are discussed. The Train Noise model (see Topic V.2.A.2) does not include ground attenuation and thus actual source heights can be used. As we have already discussed, train noise emanates from two main sources - the locomotive itself and the wheel/rail interaction noise. The locomotive noise propagates from both the exhaust stack on top of the locomotive at a height of about 15 feet above the track and from the engine casing which ranges from a height of about 6 feet up to 15 feet. As a reasonable compromise, the source height assumed by the Noise Pollution Control Section is 12 feet above the rail level.

The wheel/rail noise on the other hand issues from the reverberant space between the ground and the car underside. Again as a reasonable compromise, the source height assumed by the Noise Pollution Control Section is 2 feet above the rail level.

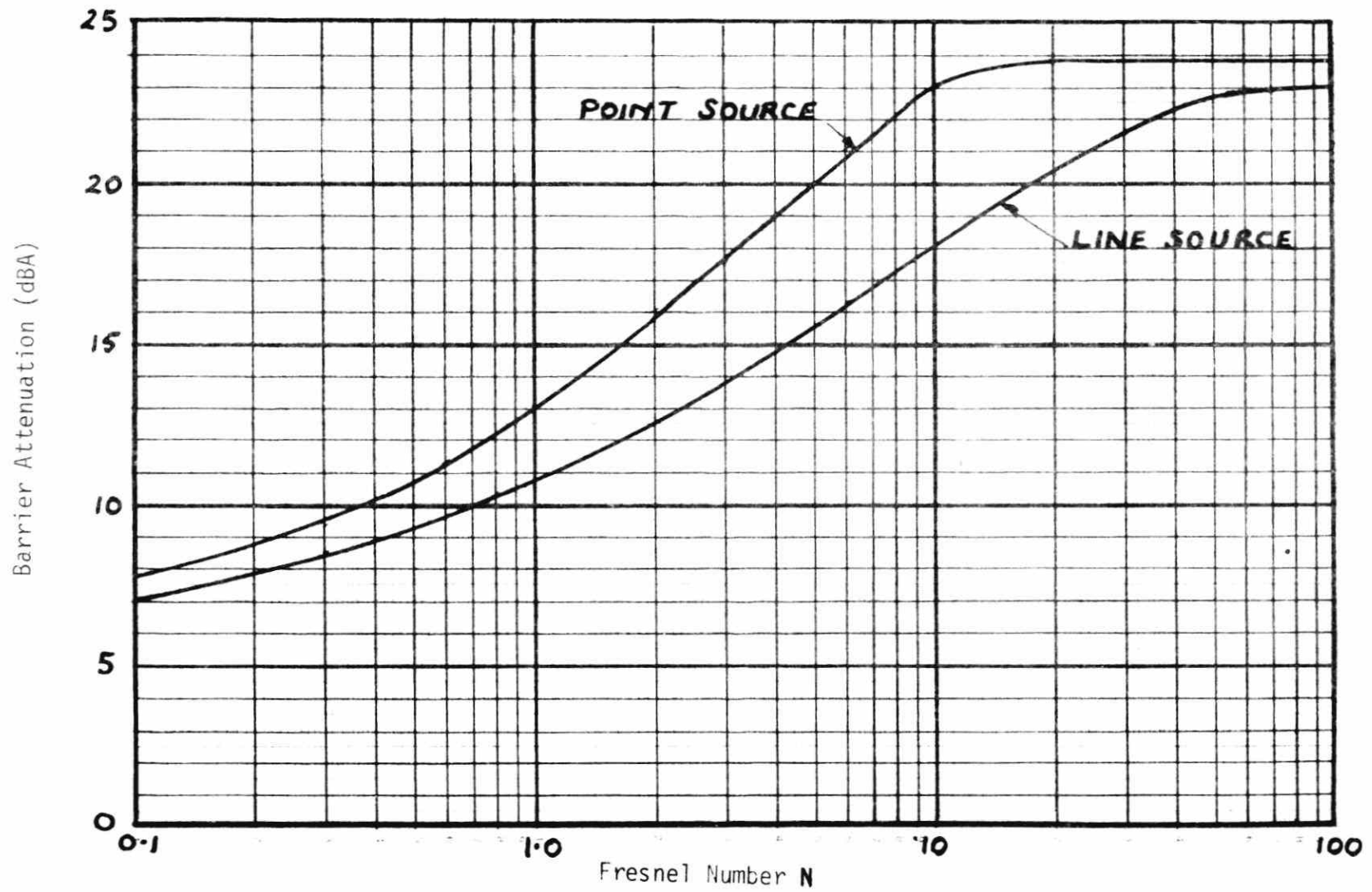


Figure V.2.C.5.: Barrier Attenuation Against Fresnel Number N

The Road Traffic Noise model (see Topic V.2.A.1) used by the Noise Pollution Control Section was derived from actual sound level measurements of traffic noise over various distances of soft ground and hence does include ground attenuation. Actual effective source heights range up to about 7 feet for high truck volumes for typical traffic flows, but in order to allow for the reduction in effective barrier attenuation because of reduced ground attenuation, the Noise Pollution Control Section assumes a source height of 10 feet regardless of truck percentage.

V.2.C.5. OTHER BARRIER CALCULATION METHODS

V.2.C.5.1. Road Traffic Noise Tables, Ministry of the Environment

The Road Traffic Noise Tables, produced by the Noise Pollution Control Section of the Ministry of the Environment contains a detailed set of barrier heights and/or building barrier heights to remove excesses above recommended sound level limits for a wide variety of road configurations and traffic flows. The barrier calculation methods used in these Tables are exactly those as presented in this topic with respect to calculation methods, representative frequency for traffic noise and effective source height for traffic noise. Results obtained using the calculation methods described here should agree closely with the Traffic Noise Tables.

V.2.C.5.2. New Housing and Road and Rail Noise - CMHC

This document contains a barrier attenuation assessment method which is based on the methods outlined above, but simplified and presented in tabular form. Barrier attenuations are presented for various differences in source and receiver height, source to barrier (or barrier to receiver) distance and barrier heights. Corrections are also provided for barriers which are not infinitely long. This reference is particularly useful in that the decrease in ground attenuation because of the presence of a barrier can be easily obtained from tables contained therein.

V.2.C.5.3. Ontario Highway Noise Prediction Methods

In this document (RR 197) a barrier attenuation calculation method is presented in very simple form. The apparent source height can be obtained knowing the truck percentage, a barrier parameter calculated and the barrier attenuation read from a table. This document does not consider the decrease in ground attenuation due to the presence of the barrier.

V.2.C.6. WORKED EXAMPLE

A person 6 feet tall is standing 25 feet from a 15 foot barrier. On the other side of the barrier is a 2 lane highway, the edge of pavement of which is 50 feet from the barrier. The ground is level from the person to the barrier but drops 3 feet at the highway edge of pavement. What is the theoretical sound attenuation due to the barrier?

Pictorially the situation is as follows:-

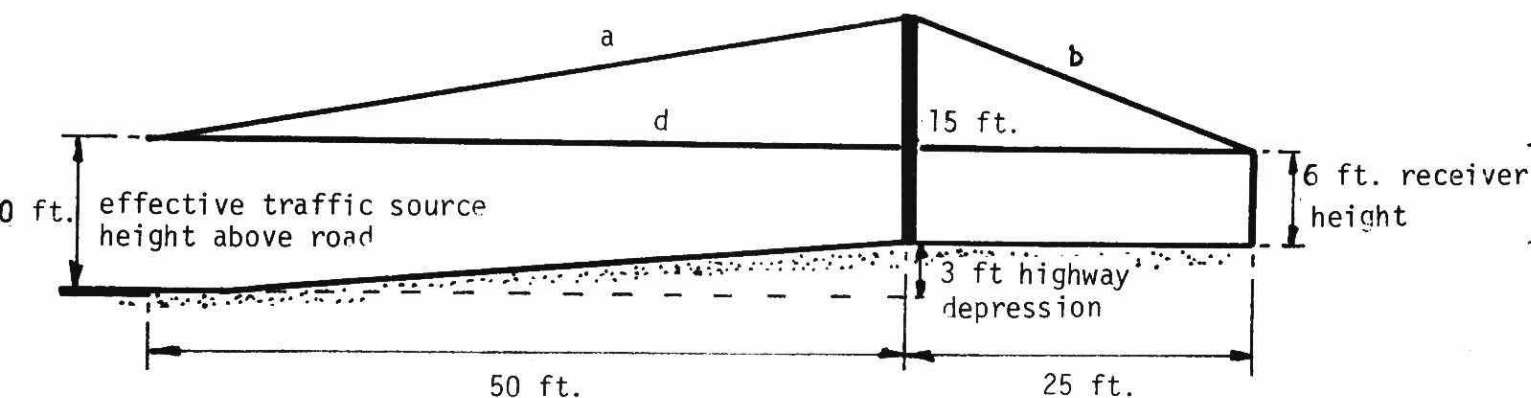


Figure V.2.C.6.: Illustration for Worked Example

Calculate a:

$$\begin{aligned} a &= \sqrt{(15 + 3 - 10)^2 + 50^2} \\ &= \sqrt{8^2 + 50^2} \\ &= \sqrt{64 + 2500} = \sqrt{2564} \\ &= 50.63 \text{ feet} \end{aligned} \quad \longrightarrow$$

Calculate b:

$$\begin{aligned} b &= \sqrt{(15 - 6)^2 + 25^2} \\ &= \sqrt{9^2 + 25^2} \\ &= 26.57 \text{ feet} \end{aligned} \quad \longrightarrow$$

Calculate d:

$$\begin{aligned} d &= \sqrt{(10 - 3 - 6)^2 + 75^2} \\ &= \sqrt{1^2 + 75^2} \\ &= \sqrt{1 + 5625} = \sqrt{5626} \\ &= 75.01 \text{ feet} \end{aligned} \quad \longrightarrow$$

Calculate PLD:

$$\begin{aligned} \text{PLD} &= a + b - d \\ &= 50.63 + 26.57 - 75.01 \\ &= 2.18 \text{ feet} \end{aligned} \quad \longrightarrow$$

Calculate Fresnel Number N:

For traffic noise, PLD calculated in feet, multiply
PLD by 0.88 (from Table V.2.C.1)

$$\begin{aligned} N &= 2.18 \times 0.88 \\ &= 1.93 \end{aligned}$$

Obtain Barrier Attenuation:

from Figure V.2.C.4, The Lower Curve for traffic noise
(line source)

$$\text{Barrier Attenuation} = 12 \text{ dBA} \quad \longrightarrow$$

SUBJECT:
ACOUSTICS TECHNOLOGY IN
LAND USE PLANNING

TOPIC: V.2.D.
BUILDING ACOUSTICS AND MATERIALS

OBJECTIVES:

Trainee will be able to:

1. Define sound transmission and sound absorption;
 2. Outline the sound transmission loss and the STC rating concept, describe the laboratory test procedure for measuring sound transmission loss and explain possible deficiencies in field conditions;
 3. Indicate factors influencing the sound transmission characteristic of a material;
 4. Explain the sound transmission process through composite constructions;
 5. Quote typical STC ratings for walls, windows, doors and ceilings. Outline various methods for improving insulation properties of building components;
 6. Use CMHC Guidelines "New Housing and Airport Noise" to evaluate insulation requirements.
-

V.2.D.1. BASIC ELEMENTS OF NOISE CONTROL IN BUILDINGS

Successful control of indoor noise originating from outdoor sources depends on understanding the behaviour of the interaction between sound waves and the materials with which they come into contact.

Two main factors affecting this interaction are the transmission of sound energy through a material and the absorption of energy at, or in the vicinity of, the material's surface. One should be careful to distinguish one from the other since, in general, they are caused by different physical properties of the material.

A material that allows only a very small transmission of sound energy is not usually efficient as an absorber of energy, and vice-versa.

V.2.D.1.1. Mechanism of Sound Transmission through Materials

When sound travelling through the air encounters a panel of a given material (such as a wall or window) the vibration of the air causes the panel to vibrate and some of the incident energy is reflected. The vibrating panel sets the air on its opposite side into vibration.

As a result, the energy transmitted through the panel appears on the other side as a sound wave of reduced intensity.

V.2.D.1.2. Sound Absorption at Material Surface

The absorption of an incident sound wave occurs at, or near, the surface of the panel. When sound waves are incident upon the surface of a panel, air flows in and out of minute pores in the material due to the pressure changes produced by the sound. Resulting frictional forces convert the sound energy into heat although the actual amount of energy dissipated is very small. The total amount of incident sound energy reflected by the wall is thus reduced, lowering in turn the reflected sound level.

It is now possible to make a clear distinction between sound transmission and absorption. The former determines how much sound energy passes through the wall and enters the room. Once in the room, the energy is further reduced by the action of the absorbents (these may also be carpeting, furnishings, etc.) which determine the final sound level in the room resulting from the entering sound energy.

A term that describes the combined action of these two effects is "noise reduction", which is defined as the difference in sound level between the exterior and the interior of the building, regardless of the mechanism of the reduction.

V.2.D.2. SOUND TRANSMISSION LOSS AND STC RATING CONCEPT

V.2.D.2.1. Sound Transmission Loss

The measure of a material's ability to attenuate the passage of sound is the sound transmission loss. By definition the Sound Transmission Loss, TL, is the ratio, expressed in dB, of the airborne sound power incident upon the panel to the sound power transmitted by the panel and radiated on the other side.

A panel having a high transmission loss would make a good insulator, a panel with a low transmission loss would be a poor insulator.

The Sound Transmission Loss of a panel is dependent on the frequency of the sound, and the angle of incidence of the sound wave upon the panel and the mass of the panel.

Analysis of the entire sound transmission loss frequency curve of a given panel provides the best method for evaluation of its sound insulating properties. However, this procedure is usually not very helpful to those not well trained in acoustics.

Therefore, a simpler method of rating partitions by comparing their sound transmission loss test curve with a "standard contour" has been worked out, to provide a complete description of insulation properties of a panel with a single value.

This single number rating is a good means of comparing the performance of different panel constructions tested under identical (or nearly identical) conditions. The number is assigned by the testing laboratory according to a carefully defined procedure and is a fairly reliable measure of comparative acoustic performance between differing panels. This number is called the Sound Transmission Class (STC) of the panel or material.

V.2.D.2.2. STC Rating Concept

To determine the STC of a test panel, the sound Transmission Loss values, as determined in the sixteen 1/3 octave bands with centre frequencies in the range of 125-4000 Hz are compared with the values of STC reference contours as shown in Figure V.2.D.1.

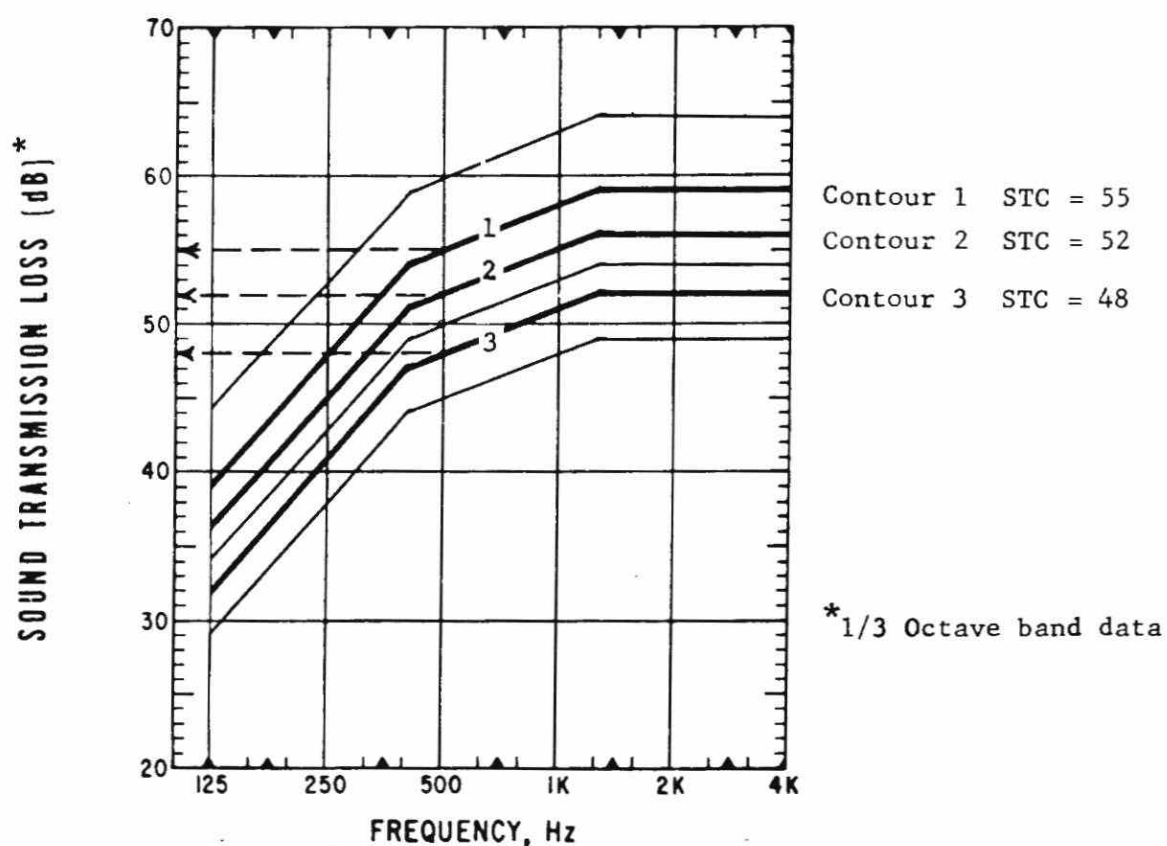


Figure V.2.D.1. Sound Transmission Class (STC) Contours

Comparison is made according to the following conditions.

1. A single unfavourable deviation (i.e. a value which falls below the contour) may not exceed 8 dB.
2. The sum of the unfavourable deviations shall not be greater than 32 dB.

Then the STC for the tested panel is the numerical value which corresponds to the sound transmission loss value at 500 Hz of the highest contour for which the above conditions are fulfilled.

Figure V.2.D.2. shows an example of determining the STC value for a 9 inch thick brick wall:

EXAMPLE

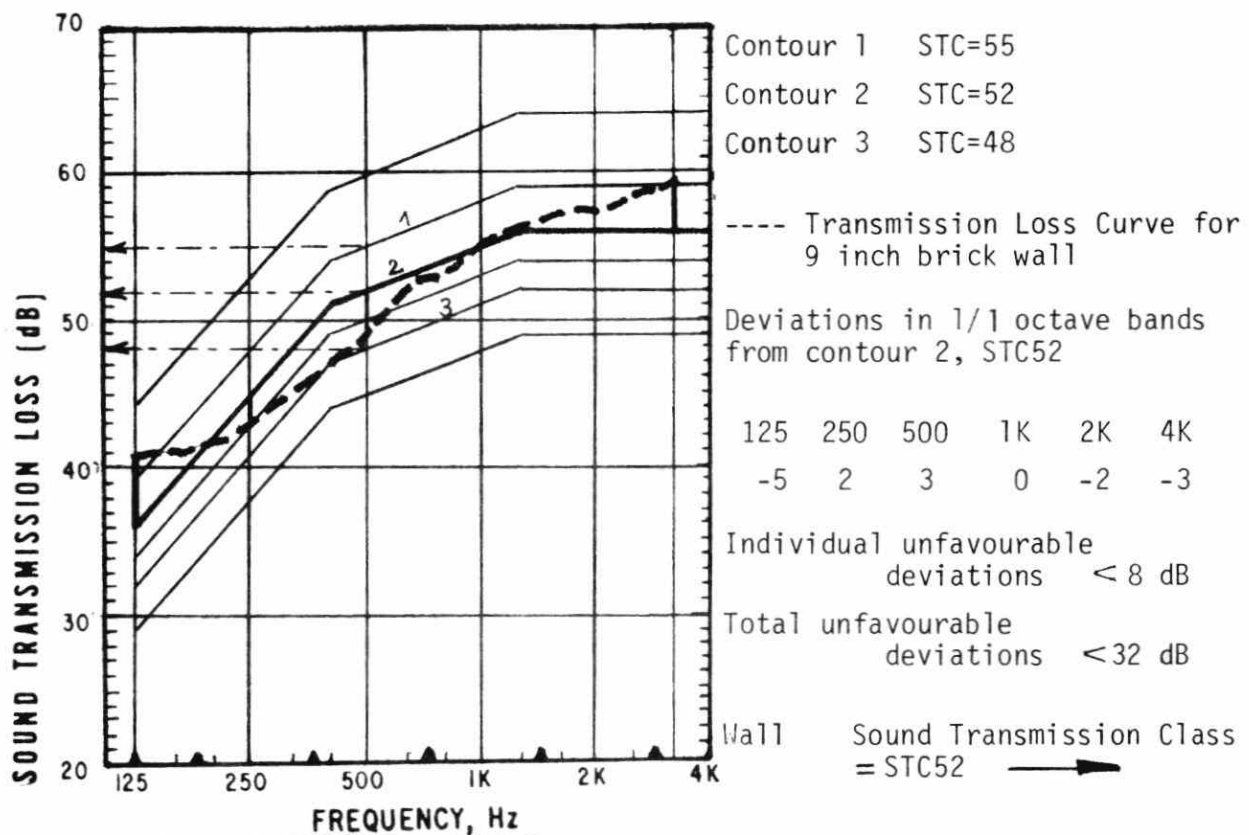


Figure V.2.D.2.: Determination of STC Value for a 9 Inch Thick Brick Wall

V.2.D.2.3. Laboratory Test Procedure for Measuring
Sound Transmission Loss

Laboratory measurement of the sound transmission loss of a building component is based on differential measurements of the sound pressure levels in two reverberant rooms separated by the test panel. An illustration of the laboratory arrangement is shown in Figure V.2.D.3. below.

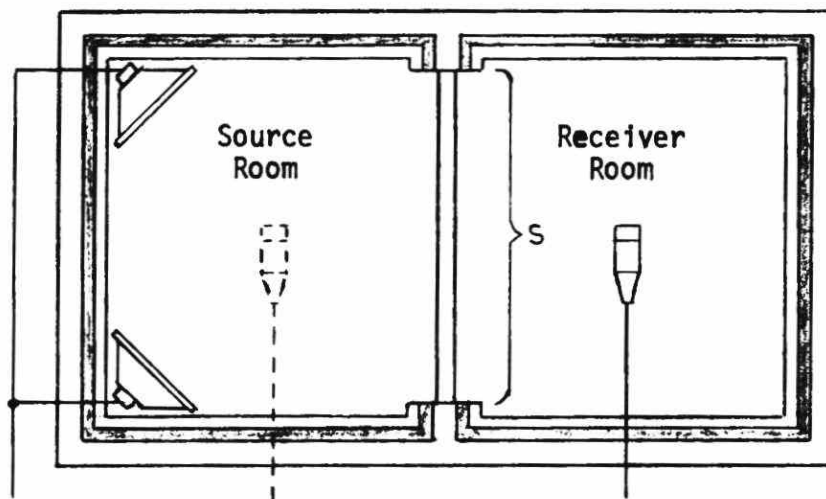


Figure V.2.D.3.: Laboratory Measurements of Sound Transmission Loss (TL)

The rooms must be designed so that the sound field in the source room is as diffuse as possible and so that sound transmission takes place only through the panel.

The sound pressure level is measured in the two reverberant rooms and the transmission loss is given by:

$$T_L = L_1 - L_2 + 10 \log \frac{S}{A} \quad \dots(V.2.D.1.)$$

where S = the area of the panel
 A = total absorption in the receiving room.
 L_1, L_2 = sound pressure levels in source and receiver room respectively.

When measurements are conducted in actual buildings some of the sound energy is transmitted not only through the wall component under test, but also through other paths; framing side walls, floors, etc. and is radiated from the wall surface of the receiving room as well as through any possible holes, cracks, in the panel or adjoining structures due to deficiencies in workmanship. This is indicated in the Figure V.2.D.4. below.

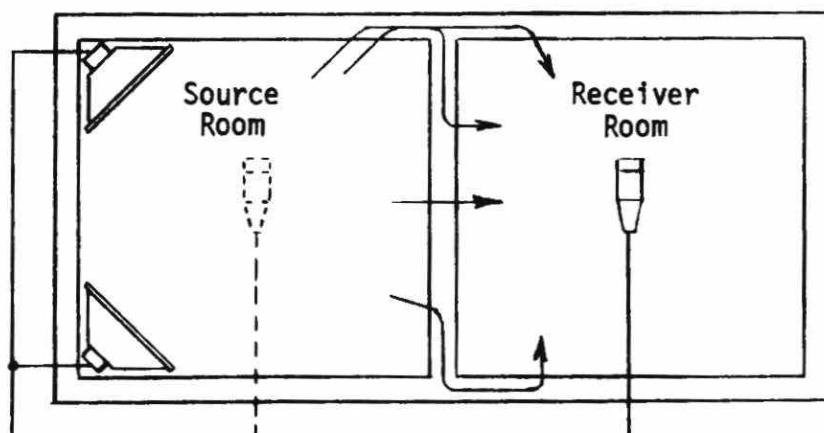


Figure V.2.D.4.: Field Measurements of Sound Insulation

Such field measurements are conducted to establish sound insulation values of completed building structures. These values are lower than the transmission losses of corresponding components as determined under ideal conditions in the laboratory.

V.2.D.3. SOUND TRANSMISSION CHARACTERISTIC OF A MATERIAL

Several factors influence the sound transmission characteristic of a material; i.e. mass per unit area of the panel, its stiffness, frequency of incident sound and angle of incidence.

For a limp wall the sound transmission is directly proportional to mass and frequency. Assuming random incidence of sound, the Transmission Loss of a panel can be expressed by:

$$TL = 20 \log (f.m) - 47 \quad \dots(V.2.D.2.)$$

where f = the frequency in H_z
 m = mass of a panel in kg/m^2

From this equation it is easy to recognize that for a doubling of either the frequency or the mass the transmission loss will increase 6 dB.

This is known as the "mass law". However, rarely does a panel act as a limp mass. Usually it moves in a more complex manner, depending upon its stiffness.

Figure V.2.D.5. below shows a typical sound insulation curve for a single panel.

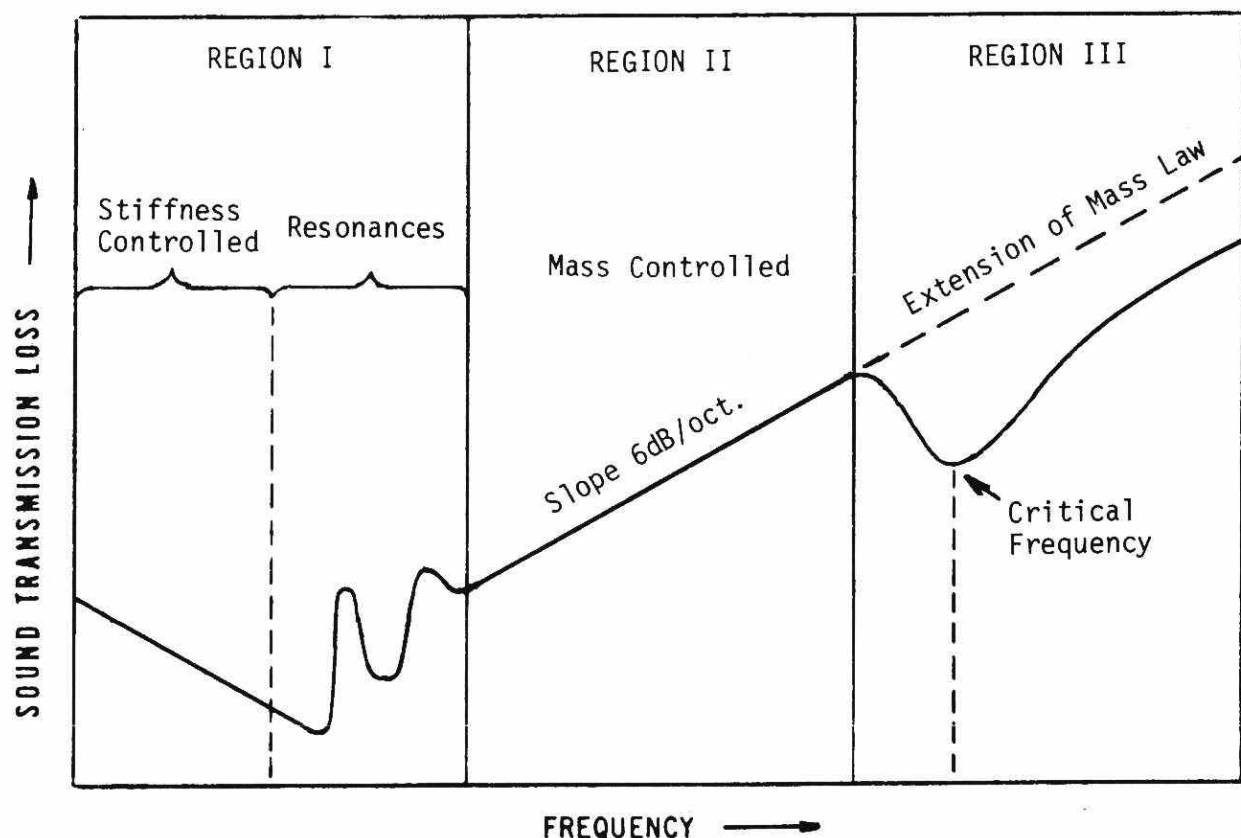


Figure V.2.D.5.: Typical Sound Insulation Curve

The curve is broadly divided into three regions. In region I, the low frequency range, the sound transmission of the panel is stiffness controlled at first and then fluctuates due to resonance effects. These resonance effects depend on panel size, mass, stiffness and on the method of fixing at the edges.

In most cases the size and material of the panel are such that the resonance frequency is well below the lowest frequency of interest.

In region II the sound transmission is primarily mass controlled and the rate of increase, theoretically 6 dB per octave, is in practice about 4.5 dB per octave.

In region III a marked drop in sound transmission loss may occur due to the so-called "coincidence effect" which occurs when the bending wave in a panel is in phase with an oblique wave front of the incident sound. This happens at some frequencies and at some angles of incidence with nearly all materials.

The lowest frequency corresponding to grazing incidence, at which the "coincidence effect" occurs is called the "critical frequency".

In general, the coincidence effect may affect sound transmission loss of a panel more seriously than resonance (occurring in region I) because it can occur well within the 100 Hz - 4000 Hz range.

V.2.D.4. SOUND TRANSMISSION PROCESS THROUGH COMPOSITE CONSTRUCTIONS

In the general case of using a panel as a sound barrier, the panel may be a wall with a door and windows and may even be built in several sections each with a different transmission loss because of different construction.

The sound transmission loss of such a composite construction depends on the relative areas and transmission losses of its components.

V.2.D.4.1. Sound Transmission Coefficient

To find the average transmission loss of the entire assembly an average transmission coefficient, t_s , has to be first determined. The sound transmission loss and sound transmission coefficient are related in the following manner:

$$TL = 10 \log \frac{1}{t_s} \quad \dots(V.2.D.3.)$$

The amount of sound power passing through a building panel component is proportional to the product of the area and sound transmission coefficient.

V.2.D.4.2. Transmission Loss of a Component

The following can be shown for a multi-component wall system:

$$t_s \cdot S = t_1 \cdot S_1 + t_2 \cdot S_2 + t_3 \cdot S_3 + \dots$$

where S = the total area of the wall

t_s = the effective sound transmission coefficient for the whole wall

t_1, t_2, t_3 = the sound transmission coefficients of the components.

$S_1, S_2, S_3, \dots$ = areas of the respective components.

$$\text{Then } t_s = \frac{t_1 \cdot S_1 + t_2 \cdot S_2 + t_3 \cdot S_3 + \dots + t_n \cdot S_n}{S}$$

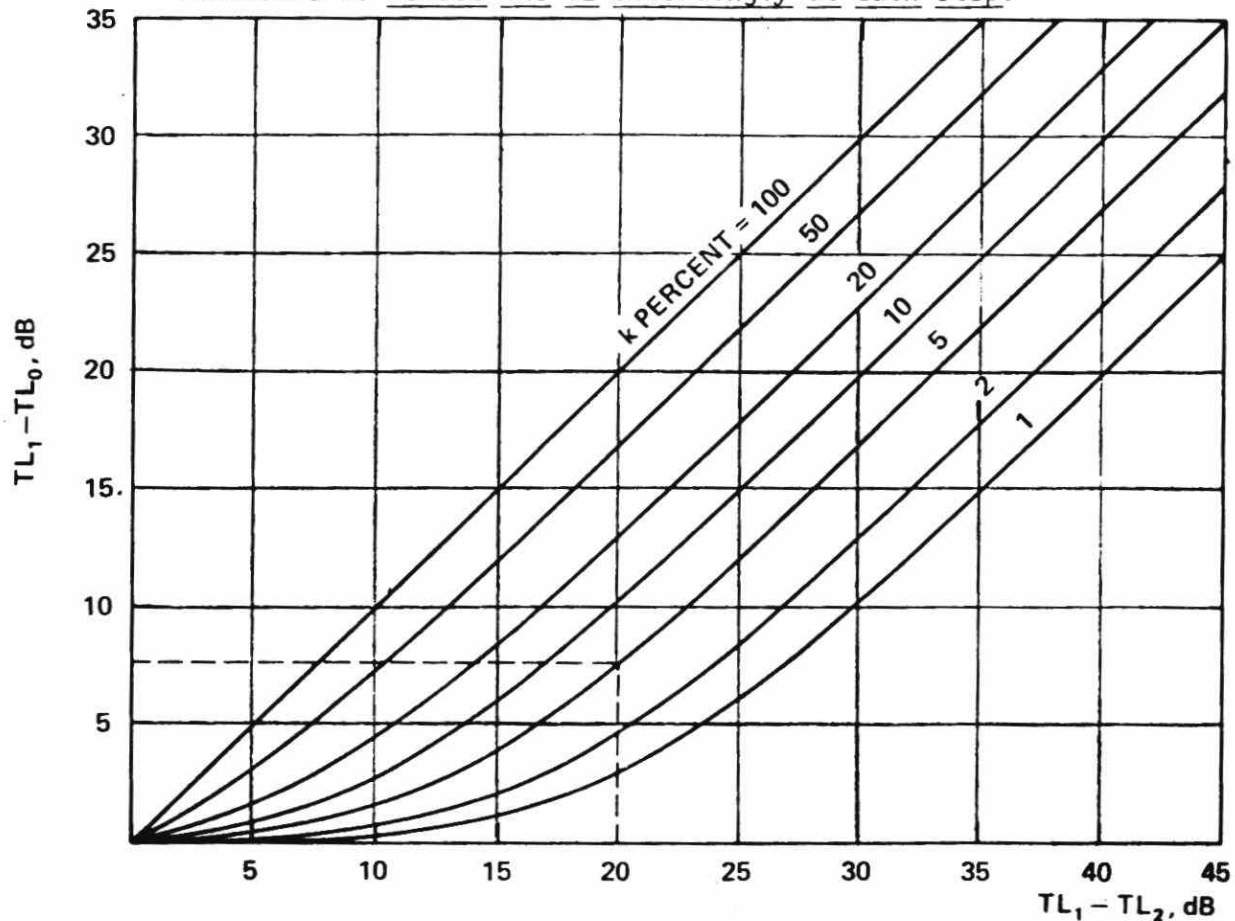
$$\text{and } TL = 10 \log \frac{S}{t_1 \cdot S_1 + t_2 \cdot S_2 + t_3 \cdot S_3 + \dots + t_n \cdot S_n} \quad \dots(V.2.D.4.)$$

A graph for the rapid calculation of the composite insulation of a wall made up of two areas is shown on Figure V.2.D.6.

Thus, the importance of each element is determined by its individual sound transmission loss (attenuation) together with the surface area which it occupies in the room. Therefore the main concern in the majority of houses are the windows, not because they occupy a large surface area, but because they themselves can have such low sound transmission loss values.

While these curves can be used only for a wall with not more than two different TL Sections, a composite wall

can be treated taking two sections at a time as long as one remembers to reduce the TL accordingly at each step.



- TL_0 = sound transmission loss of combination wall
 TL_1 = sound transmission loss of plain wall alone
 TL_2 = sound transmission loss of window/door alone
 k = percentage of wall area occupied by window/door

Figure V.2.D.6. The Effective Transmission Loss of a Composite Wall

Example of Use:

Transmission Loss of Wall, TL_1 = 50 dB

Transmission Loss of Window, TL_2 = 30 dB ; $TL_1 - TL_2 = 20$ dB

If, area window/wall k = 5%

Then, from graph $TL_1 - TL_0$ = 8 dB

Transmission Loss of Combination TL_0 = 50 - 8 dB
 = 42 dB

V.2.D.4.3. Effect of Gaps Upon TL

Figure V.2.D.6. may also be used to estimate the effect of gaps, cracks and openings on the transmission loss of doors, windows etc. In this case, if the total area of the opening is known, the opening can be considered as the weak component with a sound transmission loss of zero dB. It can be seen that it does not take a very large opening to reduce the sound transmission by a significant amount, especially for high sound transmission losses of the given component.

Suppose, for example, that a crack is left in a wall; the area of the crack constituting 1.0% of wall area. If the wall had been built with TL 45 dB, the crack will reduce the TL by 25 dB to 20 dB.

V.2.D.5. STC RATINGS FOR WALLS, WINDOWS, DOORS AND CEILINGS.

VARIOUS METHODS FOR IMPROVING THEIR INSULATION PROPERTIES

V.2..D.5.1. Walls

Different wall materials and designs vary greatly in their sound insulating properties. Figure V.2.D.7. below shows a sample of wall types ranging from the lowest to the highest sound insulation values. An estimate of the contemporary cost of these walls in dollars/sq.ft. is given for comparison of cost effectiveness.

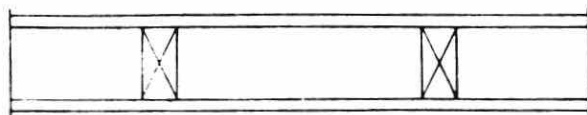
Figure V.2.D.8. provides a visual summary of some ways in which the acoustical properties can be improved.

V.2.D.5.1.1. Effect of Increased Mass and Stiffness of the Wall

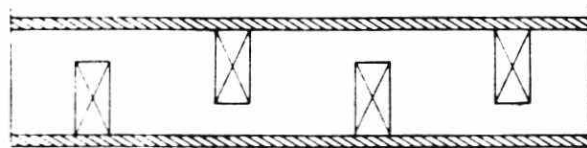
In general, the denser the wall material, the more it will reduce noise. Thus concrete walls are better insulators than wood walls of equal thickness. Increasing the thickness of a wall is another way to increase mass and improve sound insulation.

Doubling the thickness of a wall can result in as much as 6 dB reduction in noise level. However, the costs of construction tend to limit the feasibility of large increases in wall mass.

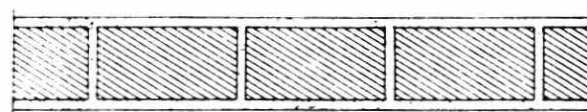
The relative stiffness of the wall material can influence its sound attenuation value. Care must be taken to avoid wall constructions that can vibrate excessively at audible frequencies and transmit exterior sound to the indoor areas.



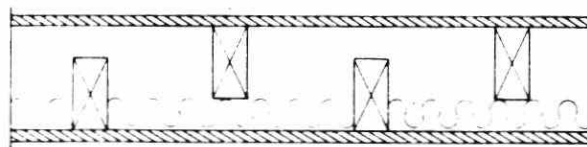
Common Stud Wall
STC = 35
cost = .87/ft²



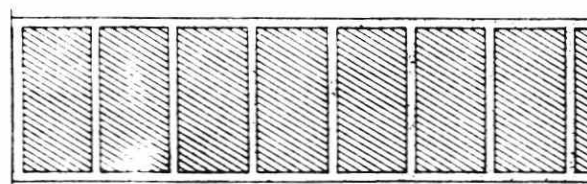
Staggered Stud Wall
STC = 39
cost = 1.12/ft²



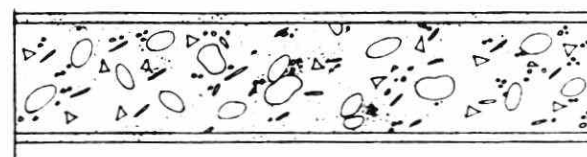
4" Brick Wall
STC = 40
cost = 2.00/ft²



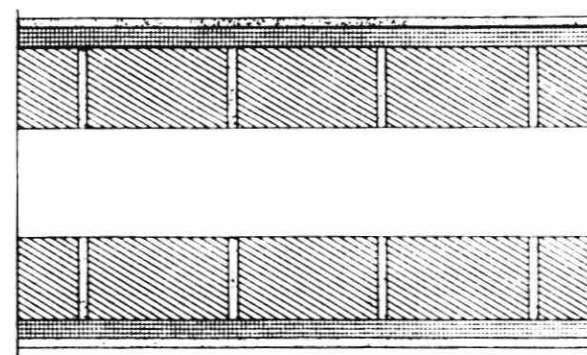
**Staggered Stud Wall
with Absorbent Blanket**
STC = 43
cost = 1.25/ft²



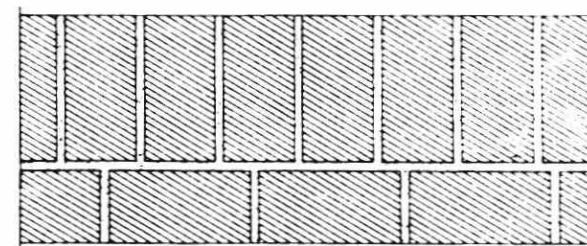
9" Brick Wall
STC = 52
cost = 2.52/ft²



7" Concrete Wall
STC = 52
cost = 1.97/ft²



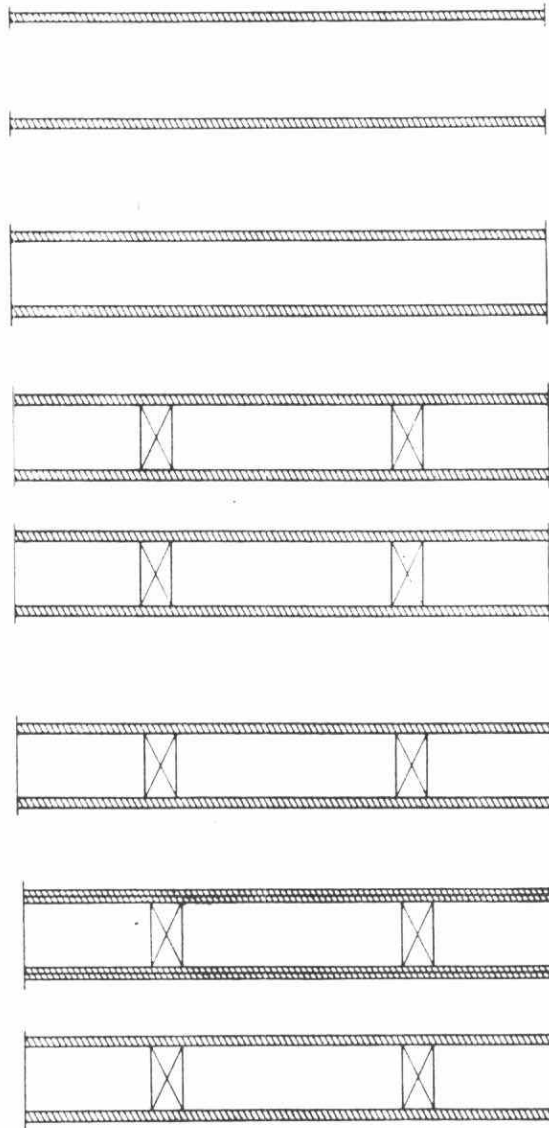
Double Brick Wall
STC = 53
cost = 2.80/ft²



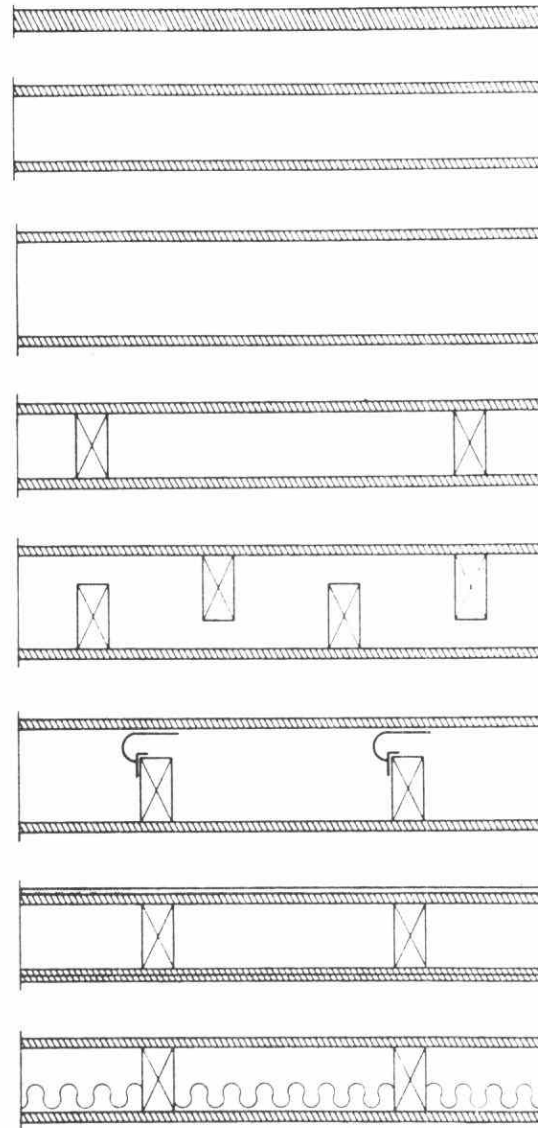
12" Brick Wall
STC = 54
cost = 4.25/ft²

Figure V.2.D.7.: Values for Common Wall Materials and Constructions

Lower sound attenuation



Higher sound attenuation



Increased mass

Use of air space

Increased width of airspace

Wide spacing between studs

Staggered studs

Use of resilient attachments

Dissimilar panels

Sound absorbing blanket in airspace

Figure V.2.D.8.: Improvement in Wall Sound Insulation Properties

V.2.D.5.1.2. Use of Cavity Walls

A cavity wall is composed of two or more layers separated by an airspace. The airspace makes a more effective sound insulator than a single wall of equal weight, thus leading to cost savings.

If a single layer of wood, for example, were used to make a wall weighing 6 lb/ft^2 , the transmission loss curve would look approximately like the dashed line shown on Figure V.2.D.9.

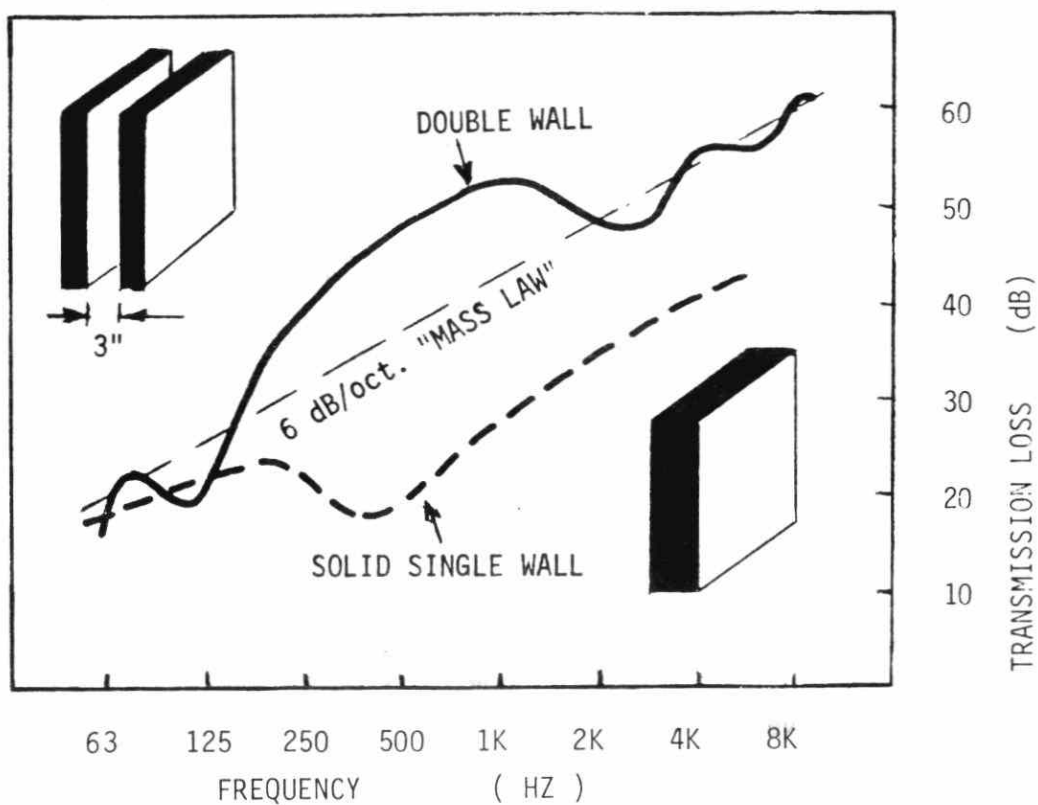


Figure V.2.D.9.: The Effect of an Air Gap Upon TL of a Wall

If that same 6 lb/ft² wall of wood were divided into two completely separate, air tight layers spaced about 3" apart, the transmission loss curve would look quite different, with several dips caused by "resonance" of the assembly at several frequencies, as shown by the solid line. The result would be that the average TL value would be significantly higher.

Increasing the width of the air space results in higher sound insulation values for a given wall. A three inch air space provides significant noise reduction, but increasing the spacing to six inches may reduce noise levels by an additional 5 dB or so.

However, extremely wide continuous air spaces are difficult to design into walls.

V.2.D.5.1.3. Increased Spacing Between Studs - Use of Staggered Studs

Double walls of wood or metal section frame construction may include split or staggered studs. In such construction the air, by virtue of its compressibility, acts as the spring element or vibration isolator. A wider air space provides a softer spring action which results in greater sound insulation.

Also the increased spacing between studs reduces excessive coupling between the two walls and results in a reduction of acoustic energy transmitted through such a structure. For example; in a common stud wall construction, a 24 inch stud spacing gives a 2 to 5 dB increase in STC over the common 16 inch spacing. Sound transmission loss can be increased further by attaching each stud to only one panel and alternating between the two panels. See Figure V.2.D.8.

V.2.D.5.1.4. Use of Resilient Materials - Use of Dissimilar Leaves

Any rigid coupling between two walls of double leaf construction will lower its ability to reduce the amount of the transmitted energy. Panels made up of resilient layers such as fiber board, glass fiber board, resilient clips as well as semi-resilient attachments are simple to insert and are relatively inexpensive. Their use can raise the STC rating of the assembly by 2 to 5 dB.

If the leaves are made of different materials and/or thicknesses, the sound reduction qualities of the wall are also improved.

V.2.D.5.1.5. Use of Sound Absorbent Liners

Also known as insulation blankets, these can increase sound attenuation when placed in the air space of a double wall. Sound absorbent liners tend to minimize the sound energy buildup in the hollow reverberant wall cavities, particularly at the higher frequencies.

Made from sound absorbing materials, such as mineral or rock wool, fiberglass, hair felt or wood fibers, sound absorbent liners can improve wall performance as much as 10 dB.

They are mainly effective in relatively lightweight frame construction rather than in heavy masonry construction. However, the use of insulation blankets in airspaces of common stud walls contribute little toward improved sound insulation. Owing to the rigid ties of the stud framing to the wall surfaces, the entire wall behaves like a diaphragm under vibration excitation and transmits the sound readily; thus the effectiveness of the insulation blanket is "short circuited".

Sound absorbent liners are also heat energy insulators and their use should be encouraged wherever possible as a conservation measure.

V.2.D.5.1.6. Proper Sealing and Installation of Walls

If the sound insulation of a high performance wall is to be realized, the wall must be of "air tight" construction and well sealed at the perimeter. Care must be exercised to seal all openings, gaps, holes, joints and penetration of piping. Even hairline cracks which might occur, particularly at the adjoining wall, floor and ceiling edges, during the drying out period or building settlement should be re-sealed. See Figure V.2.D.10. below.

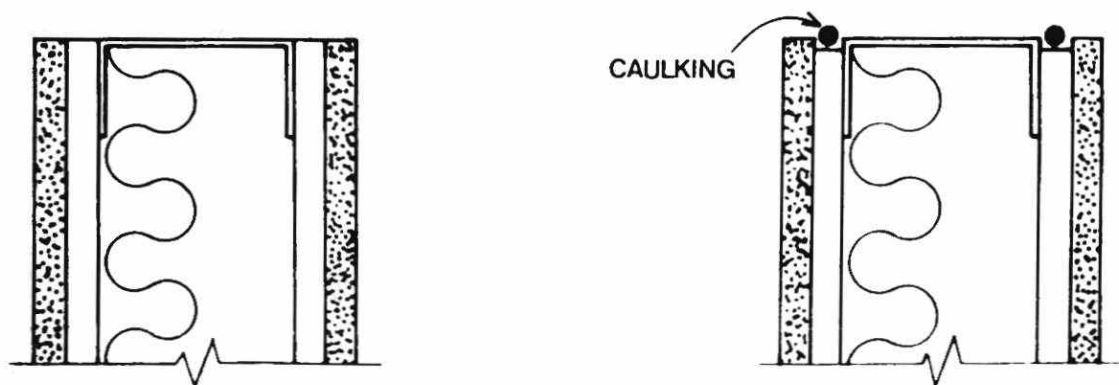


Figure V.2.D.10 Example of Good Edge Sealing Practice

A substantially greater amount of sound energy is transmitted through a crack than would be normally expected on the basis of its area as illustrated in V.2.D.4.3.

Also, proper installation of the wall requires that one should try to keep coupling or rigid ties to other structural assemblies at an absolute minimum. The purposes of decoupling the wall is to break up, or minimize, the sound flanking paths transmitted through the structure from outside or from one room to another.

V.2.D.5.2. Windows

Sound enters a building through its acoustically weak points and windows are one of the weakest parts of the wall. An open or weak window will severely negate the effect of acoustically very strong walls.

For example, if a wall with an STC rating 45 contains a window with an STC rating 26 covering only 20% of its area, the overall STC of the composite wall will be STC 33, a reduction of 12 dB (check with Figure V.2.D.6.).

The following techniques can be used to reduce noise admitted through windows.

V.2.D.5.2.1. Closed Windows

The first step in reducing unwanted sound is to close and seal the windows. The greatest amount of sound insulation can be achieved if windows are permanently sealed. However, openable acoustical windows have been developed which are fairly effective in reducing indoor noise levels.

Whether or not the sealing is permanent, closed windows necessitate the installation of an air ventilation or air conditioning system. If a window must be openable, special seals are available which will allow the window to be opened.

V.2.D.5.2.2. Reduced Window Size

The smaller the window, the greater the net sound transmission loss of the total wall area of which the window is a part.

Reducing the window size is a technique used because it precludes the cost of expensive acoustical windows.

However, this technique is not very effective in reducing noise: e.g. reducing the proportion of window to wall size from 50% to 20% reduces noise inside by only 3 dB.

Table V.2.D.1. illustrates STC ratings for a composite wall with various percentages of glass area.

Window Type	Single Glazing	Double Glazing	Special Construction Perm. Sealed
Window STC	25	30	40
Wall STC	35 50	35 50	35 50
% Glass Area			
0	35 50	35 50	35 50
10	32 35	34 40	35 47
25	30 31	33 36	36 44
50	28 28	32 33	37 42
75	26 26	31 31	38 41
100	25 25	30 30	40 40

Table V.2.D.1. STC values for a composite wall with various percentages of glass area.

It should be mentioned that the Ontario Building Code requires a certain minimum window-to-wall size ratio.

V.2.D.5.2.3. Increased Glass Thickness

Improved sound insulation can be obtained by increasing the weight (i.e. thickness) of the glass since glass reduces noise by the mass principle.

Figure V.2.D.11. shows the variation of mean sound insulation value with glass thickness.

All the values in the graph are for sealed windows, tested in the frequency range from 100 Hz to 3200 Hz.

It can be seen from the graph, that $\frac{1}{2}$ inch (12.7 mm) thick glass has a maximum STC rating of 33 compared to an STC rating of 26 for ordinary 3/16 inch thick glass.

However, increase of glass thicknesses are only practical up to a certain point, when STC increases become too insignificant to justify the cost. For example, a $\frac{1}{2}$ inch thick glass can have an STC of 33; increasing the thickness to 3/4 inch (19 mm) only raises the STC to 35.

A double glass pane acoustical window consisting of two 32 oz. glass panes (3.4 mm) separated by a 4 inch air space will have an STC up to 35 depending on the type of sealant, frame construction, etc. A considerable improvement of window insulation can be achieved by laminating a single pane with a thick transparent plastic, which is both noise and shatter resistant. Laminated "sound-retarding" glass is a sophisticated form of safety glass, employing multiple layers of thin glass, laminated with thick, soft layers of plastic to make a monolithic pane, ranging in thickness from just over 1/4 inch to well over 1 inch. The latter one inch composite thickness may well have an STC 40 rating!

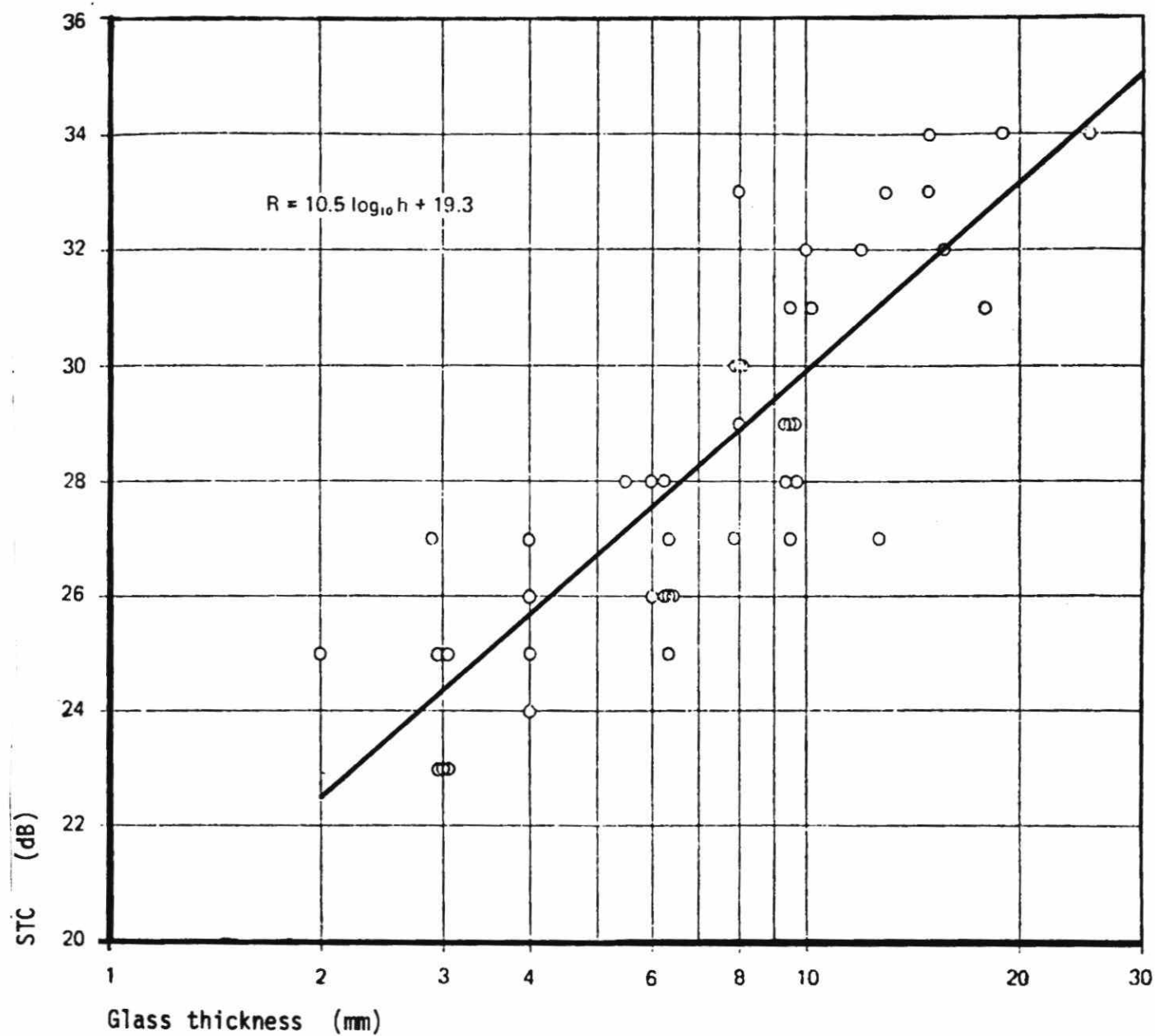


Figure V.2.D.11.: Increase of STC with Thickness for Glass

V.2.D.5.2.4. Double Glazed Windows

Double glazed windows are paired panes, separated by an air space, hung in a special frame. Generally, the performance of the double glazed window may be increased with:

- increased airspace width
- increased glass thickness
- proper use of sealings
- slightly dissimilar thickness of the panes
- slightly non-parallel panes.

Sound insulation generally increases with increased gap between the glass panels. However, experimental studies of double glazed units have shown that sound insulation approaches a maximum with an optimum spacing of 100 mm and only a small increase occurs thereafter with greater air spacing.

In all double and multiple glazing systems, lining the sides of the air space with sound-absorbent materials reduces the resonances within the cavity, resulting in a worthwhile improvement in sound insulation. The increase in insulation will be dependent on the dimensions of the air space and the properties of the absorbent material.

It is also important that the panes of a double glazed window be mechanically isolated from each other. Where the panes are fixed in separate frames, the frames should be so mounted that vibrations from one cannot be easily transmitted to the other.

As in the case of all windows, proper sealing is extremely important. To achieve an STC above 43, double glazed windows should be sealed permanently. If the windows must be openable, there are special frames and sealers available which allow a maximum STC of 43.

To further improve the sound insulation between double glazed panes, the panes could be of different thicknesses, different weights and slightly non-parallel to each other. This prevents acoustical coupling and minimizes resonance effects. Figure V.2.D.12. shows examples of windows with panes of different thickness, and with non-parallel panes.

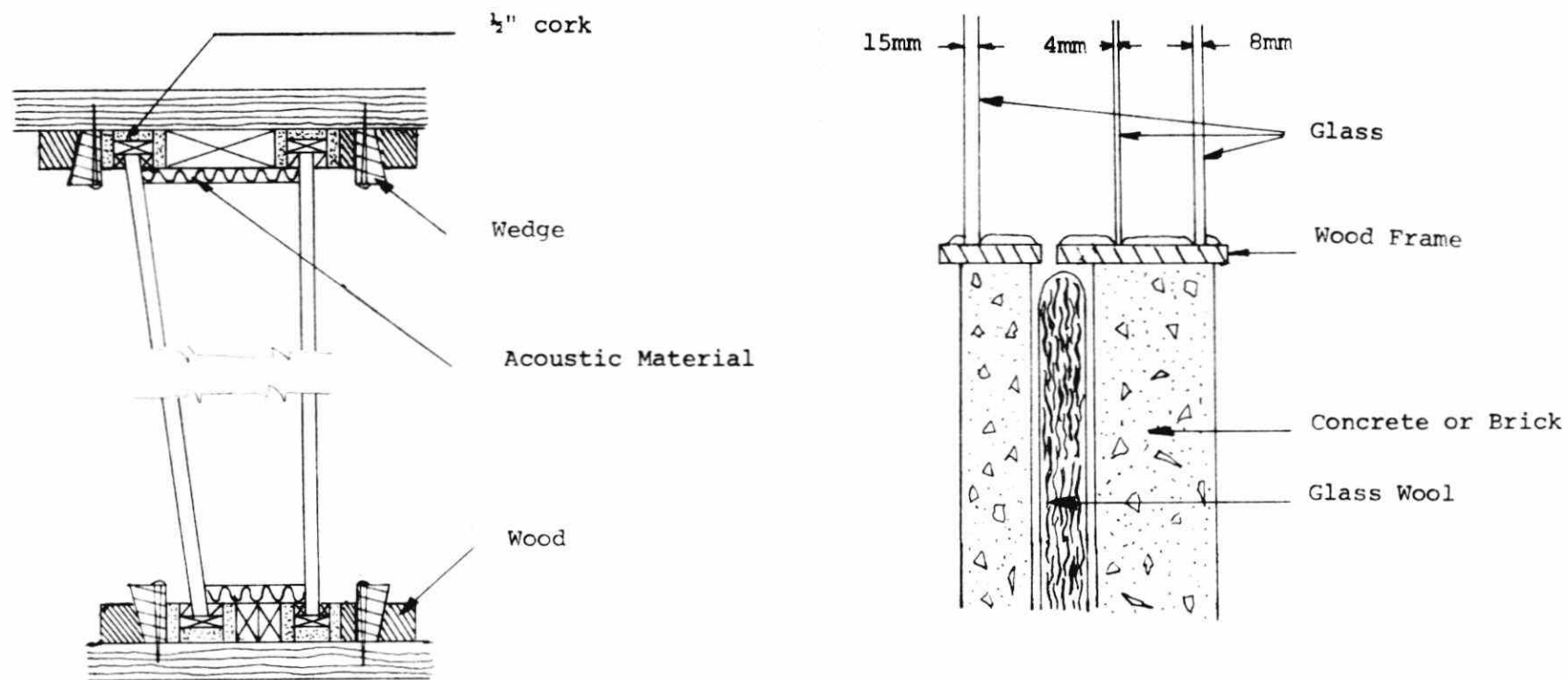


Figure V.2.D.12.: Sound Retardant Windows of Special Design

The construction of such glazing systems are usually expensive and, as a result, are only justified in extremely noisy environments and where all the other acoustical improvements have already been made.

V.2.D.5.2.5. Practical Window Insulation Values

Because of differences in constructional detail, fixing, variations in the window size and room absorption, it is not possible to give general insulation figures which are valid for all cases.

Table V.2.D.2. below shows the practical field insulation values that can be expected from various types of windows. They are mean values, each representing a possible range of 6 dB (± 3 dB) and can be used to give reasonably accurate results provided that the window is, at least, about 20.0 ft.² in area and forms part of a room of normal size with ordinary furnishing.

The values in the Table are based on measured data. Other glazing systems for which no measured values were available are given values obtained by interpolation or estimation and these are marked in the Table by asterisks.

WINDOW TYPE	INSULATION
<u>Normal Opening Lights Single Glazing, Closed</u>	
24 oz to 1/4 inch glass	18
1/2 inch glass	*22
<u>Sealed or Fixed Single Glazing</u>	
24 oz. glass	23
32 oz. glass	25
3/16 inch glass	*26
1/4 inch glass	26 - 28
3/8 inch glass	28 - 30
1/2 inch glass	31 - 33
3/4 inch glass	35
1 inch glass	37

WINDOW TYPE	INSULATION
<u>Normal opening lights, double glazing, (closed)</u>	
24 - 32 oz glass with 4 inch air space without absorbent between panes.	*22
24 - 32 oz glass with 4 inch air space with absorbent between panes.	*28
$\frac{1}{4}$ inch glass with 4 inch air space with absorbent between panes.	*30
<u>Sealed or Fixed Double Glazing</u>	
24 oz. glass with less than 2 inch air space with absorbent	24
32 oz. glass with less than 2 inch air space without absorbent	28
32 oz. glass with less than 2 inch air space with absorbent	*29
32 oz. glass with 2 inch air space without absorbent	29
32 oz. glass with 2 inch air space with absorbent	*32
32 oz. glass with 4 inch air space without absorbent	*30
32 oz. glass with 4 inch air space with absorbent	34
$\frac{1}{4}$ inch glass with less than 2 inch air space without absorbent	*33
$\frac{1}{4}$ inch glass with less than 2 inch air space with absorbent	34
$\frac{1}{4}$ inch glass with 2 inch air space without absorbent	*33
$\frac{1}{4}$ inch glass with 2 inch air space with absorbent	*36
$\frac{1}{4}$ inch glass with 4 inch air space without absorbent	*34
$\frac{1}{4}$ inch glass with 4 inch air space with absorbent	38

WINDOW TYPE	INSULATION
<u>Laminated Single Glazing, Sealed or Fixed</u>	
¼ inch laminated glass,	31
9/32 inch laminated glass	36
½ inch laminated glass	38
¾ inch laminated glass	39
1 inch laminated glass	41

Table V.2.D.2. STC Ratings for Various Windows

V.2.D.5.3. Doors

The transmission loss of doors obeys the same mass law that holds true for single panels. Generally the greater their density the better their sound insulating properties.

However, a good acoustical seal around the edges and insulation in the cavity of a double leaf door are both essential. Improper sealing around the edges of even thick doors will result in poor sound insulation and, therefore, care should be taken that a good positive seal exists between the door frame and the door panel.

The Table below gives the STC rating of typical designs of exterior doors, separately for closed and for sealed conditions;

Type of Door	Closed	Sealed
Wood, solid core 1-3/4 inch, 3.9 lb/sq.ft.	27	30
Same wood, solid core with aluminum storm door	34	42
Wood, hollow core 1-3/4 inch, 1.25 lb/sq.ft.	20	21
Steel, flush panel with foamed- in polyurethane, 3.2 lb/sq.ft.	27	28
Fiberglass-reinforced, plastic with foamed-in polyurethane, 2.35 lb/sq.ft.	25	26

Table V.2.D.3. STC Ratings for Doors

The relatively low sound transmission loss of doors will significantly reduce acoustically stronger walls. For example, the common hollow door taking up 20% of a wall having an STC of 48, will reduce the composite STC of such a wall structure to STC 27. (Check using Figure V.2.D.6.).

The alternative solution to using an improved, expensive door is to eliminate doors wherever possible from the severely noise impacted walls and place them in other more shielded walls.

V.2.D.5.4. Ceilings and Roof Decks

Acoustical treatment of ceilings and roof decks is not usually necessary unless the noise is extremely severe and the sound waves pass over the building roof.

Ceilings are usually considered absorptive systems, while roof decking will provide sound barrier properties since there will generally be a layer of tar, tar paper, gravel or other materials to weatherproof the construction. Various types of roof deck systems come in different thickness and provide a different degree of sound absorption and sound attenuation depending on this thickness and on the type of built up roof-backing used.

In general, an ordinary plaster ceiling should provide adequate sound insulation, except in extremely severe cases.

V.2.D.6. CMHC GUIDELINES ON INSULATING HOUSES AGAINST AIRCRAFT NOISE

Once the noise levels outside the building are established, the requirements for adequate sound insulation for all the possible transmission paths into the building can be evaluated. Such evaluation, however, involves tedious calculations of the sound energy transmitted by various paths at various frequencies in order to arrive at a detailed picture of the effective sound insulation required for the various rooms in a building. To simplify this procedure the National Research Council of Canada has developed a simple technique to evaluate the insulation requirements for residential housing located near airports. CMHC guidelines can be also easily applied to road and rail traffic noise. The appropriate building components for any room are selected on the basis of the Acoustic Insulation Factor (AIF) which is simply related to the difference in perceived noise level (outside and inside), as follows:

$$\begin{aligned} \text{AIF} &= \text{NEF outdoors} - \text{NEF indoors} + 10 \log_{10} N \quad \dots(\text{V.2.D.5.}) \\ N &= \text{the number of components forming the exposed facade.} \end{aligned}$$

This Factor, which takes account of several variables, including the number of components forming the envelope of the room, provides the link between the N.E.F. (Noise Exposure Forecast Number) indicating the sensitivity zone for aircraft flyovers and those components which will give adequate sound insulation. (For a discussion of Aircraft Noise see V.5.A.)

Typically, the outdoor sound may penetrate a room by several possible paths; one or more walls, windows, doors and perhaps the roof. To sum up the contributions of these various paths requires a complicated calculation back and forth between AIF's and absolute sound powers. This complication is removed by postulating that all paths carry equal sound power. Then the AIF's (corrected for area) must simply be equal.

Although in principle one could compensate for a low AIF in one path by a superior value in another, the lowest ones always dominate, and the equal power postulate may thus be conservative by one or two points at most.

If there are several transmission paths, each must carry less power than if there were only one path. This is taken into account by increasing the AIF requirement by three points for two paths, five for three paths, six points for four paths and so on.

The result is an optimum design that keeps the relative importance of the major construction elements in perspective. The one parameter allowed to be altered over wide limits is the ratio of window to wall area. The final step is to provide a series of tables of AIF values for typical building components.

The same AIF may be adapted with a slight adjustment to the road and rail noise case, by putting:

$$\text{AIF} = L_A \text{ outdoors} - L_A \text{ indoors} + 10 \log_{10} N + 2 \quad \dots(\text{V.2.D.6.})$$

where L_A = A-weighted sound level.

N = the number of components forming the exposed facade.

V.2.D.6.1. Detailed Procedure

The appropriate building components for any room in a dwelling are selected as follows:

- (a) Determine by reference to the NEF contour map for the airport concerned, the NEF contour passing through the building location. If the location falls between two NEF values the higher value should be used.
- (b) Determine whether the required AIF is for the components of a bedroom or other room.
- (c) Determine the number of components which make up the exterior envelope of the room e.g. windows, walls, ceiling/roofs and doors. It should be noted that:
 - (i) where windows and exterior doors do not form part of the exterior envelope of a room, they must be treated and included as a component of all rooms which have an opening or doorway opposite or adjacent to them.
 - (ii) Since the AIF is related to the total area of each type of component, the number of individual units of each type does not affect the determination of the AIF. For example, 6 individual windows in a room would be counted as one component and their total area used in the calculations of AIF.

- (d) Determine the Acoustic Insulation Factor from the following Table V.2.D.4. (also see CMHC guidelines).

Number of components, N, forming the room envelope	AIF for	
	Bedrooms	Other rooms
1 component	NEF + 3	NEF - 2
2 components	NEF + 3 + 3	NEF - 2 + 3
3 components	NEF + 3 + 5	NEF - 2 + 5
4 components	NEF + 3 + 6	NEF - 2 + 6

Table V.2.D.4. Selection of AIF Values

- (i) Adjustment factors of NEF + 3 and NEF - 2 for the sound insulation required in the building envelope have been recommended by the National Research Council of Canada based particularly on a review of studies related to thresholds of annoyance and speech interference. They are related to acceptable indoor noise levels equivalent to - 3 NEF units and + 2 NEF units for bedrooms and other rooms respectively. The difference of 5 units between the two types of accommodations allows for the desirability of having less noise in sleeping accommodation (bedrooms).
- (ii) It can be seen from the Table that additional adjustments apply to those outlined in (i) above when there is more than 1 component, namely:
 3 points have to be added where there are 2 components,
 5 points have to be added where there are 3 components, and
 6 points, where there are 4 components.
 These adjustments are made because as more components are added to the exterior room envelope, the total insulation is reduced.

leq at Building Wall	Bedrooms								Living, Dining, Recreation								Kitchen, Bathroom							
	Number of Components Forming the Room Envelope																							
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
55	22	25	27	28	29	30	31	31	17	20	22	23	24	25	26	26	12	15	17	18	19	20	21	21
56	23	26	28	29	30	31	32	32	18	21	23	24	25	26	27	27	13	16	18	19	20	21	22	22
57	24	27	29	30	31	32	33	33	19	22	24	25	26	27	28	28	14	17	19	20	21	22	23	23
58	25	28	30	31	32	33	34	34	20	23	25	26	27	28	29	29	15	18	20	21	22	23	24	24
59	26	29	31	32	33	34	35	35	21	24	26	27	28	29	30	30	16	19	21	22	23	24	25	25
60	27	30	32	33	34	35	36	36	22	25	27	28	29	30	31	31	17	20	22	23	24	25	26	26
61	28	31	33	34	35	36	37	37	23	26	28	29	30	31	32	32	18	21	23	24	25	26	27	27
62	29	32	34	35	36	37	38	38	24	27	29	30	31	32	33	33	19	22	24	25	26	27	28	28
63	30	33	35	36	37	38	39	39	25	28	30	31	32	33	34	34	20	23	25	26	27	28	29	29
64	31	34	36	37	38	39	40	40	26	29	31	32	33	34	35	35	21	24	26	27	28	29	30	30
65	32	35	37	38	39	40	41	41	27	30	32	33	34	35	36	36	22	25	27	28	29	30	31	31
66	33	36	38	39	40	41	42	42	28	31	33	34	35	36	37	37	23	26	28	29	30	31	32	32
67	34	37	39	40	41	42	43	43	29	32	34	35	36	37	38	38	24	27	29	30	31	32	33	33
68	35	38	40	41	42	43	44	44	30	33	35	36	37	38	39	39	25	28	30	31	32	33	34	34
69	36	39	41	42	43	44	45	45	31	34	36	37	38	39	40	40	26	29	31	32	33	34	35	35
70	37	40	42	43	44	45	46	46	32	35	37	38	39	40	41	41	27	30	32	33	34	35	36	36
71	38	41	43	44	45	46	47	47	33	36	38	39	40	41	42	42	28	31	33	34	35	36	37	37
72	39	42	44	45	46	47	48	48	34	37	39	40	41	42	43	43	29	32	34	35	36	37	38	38
73	40	43	45	46	47	48	49	49	35	38	40	41	42	43	44	44	30	33	35	36	37	38	39	39
74	41	44	46	47	48	49	50	50	36	39	41	42	43	44	45	45	31	34	36	37	38	39	40	40
75	42	45	47	48	49	50	51	51	37	40	42	43	44	45	46	46	32	35	37	38	39	40	41	41

Table V.2.D.5 AIF Required by CMHC for the Road and Rail Traffic Noise Case (For values recommended by the Noise Pollution Control Section subtract 5 AIF).

	Percentage of window area to total floor area of room												Single glazing, or factory- sealed double glazing	Type of Window Double window with indicated space (inches) between glass			
	4	5	6.3	8	10	12.5	16	20	25	32	40	50		0.8 to 1.5	1.6 to 2.5	2.6 to 3.5	3.6 up
Acoustic Insulation Factor	35	34	33	32	31	30	29	28	27	26	25	24	W1				
	36	35	34	33	32	31	30	29	28	27	26	25	WT1				
	37	36	35	34	33	32	31	30	29	28	27	26	W2				
	38	37	36	35	34	33	32	31	30	29	28	27	WT2				
	40	39	38	37	36	35	34	33	32	31	30	29	W3 or W4	W1 - W1			
	41	40	39	38	37	36	35	34	33	32	31	30	W5	W2 - W2			
	42	41	40	39	38	37	36	35	34	33	32	31		W1 - W1			
	43	42	41	40	39	38	37	36	35	34	33	32		W2 - W3	W1 - W2	W1 - W1	
	44	43	42	41	40	39	38	37	36	35	34	33		W3 - W3	W2 - W2	W1 - W2	
	45	44	43	42	41	40	39	38	37	36	35	34		W2 - W5		W2 - W2	
	46	45	44	43	42	41	40	39	38	37	36	35	W6 (sealed)		W2 - W3 or WT1 - W1		W1 - W1
	47	46	45	44	43	42	41	40	39	38	37	36			W3 - W3	W2 - W3	W1 - W2
	48	47	46	45	44	43	42	41	40	39	38	37	W7 (sealed)		W5 - W5	W3 - W3 or W4 - W4	W2 - W2
	49	48	47	46	45	44	43	42	41	40	39	38			WT2 - W1	W5 - W5	WT1 - W1 or W2 - W3
	50	49	48	47	46	45	44	43	42	41	40	39			WT1 - W5	WT2 - W1	W3 - W3 or W4 - W4
	51	50	49	48	47	46	45	44	43	42	41	40			W5 - W6 or WT2 - W5	WT1 - W5	W5 - W5 or WT2 - W1
	52	51	50	49	48	47	46	45	44	43	42	41				WT2 - W5	WT1 - W5
	53	52	51	50	49	48	47	46	45	44	43	42					WT2 - W5

Note: Where the calculated percentage window area is not presented as a column heading, the nearest percentage column in the table should be used.

Source: National Research Council, Ottawa, February 1977.

- Explanatory Notes:
- 1) Glazing: 1 denotes 18 oz. glass
2 denotes 24 oz. glass
3 denotes 32 oz. glass
4 denotes 3/16" glass
5 denotes 1/4" glass
6 denotes 3/8" glass
7 denotes 1/2" laminated glass
 - 2) W denotes single glazed windows (e.g., W3 denotes a single pane of 32 oz. glass).
WT denotes factory-sealed double glazing with panes separated 0.75 in. or less (e.g., WT1 has two panes of 18 oz. glass).
W-W denotes double glazing (e.g., W2-W3 denotes double glazing with one pane of 24 oz. glass and one pane of 32 oz. glass with spacing between the panes as indicated at the top of the column).
WT-W denotes factory-sealed double glazed unit plus storm window (e.g., WT1-W2 denotes a factory-sealed unit with two panes of 18 oz. glass plus a storm window of 24 oz. glass with space between as indicated at the top of the column).
 - 3) Except as noted, data are for well-fitted weatherscrapped openable units. The AIF applies only when all windows are closed.
 - 4) Window types W6 and W7 are for fixed units sealed to the frame. For any other type of window fixed and sealed to the frame, add three (3) to the AIF given in the table.

Table V.2.D.6.A.: Acoustic Insulation Factor (AIF) for Various Types of Windows

	Percentage of exterior wall area to total floor area of room											Type of Exterior Wall
	16	20	25	32	40	50	63	80	100	125	160	
	45	44	43	42	41	40	39	38	37	36	35	EW1
	46	45	44	43	42	41	40	39	38	37	36	EW2
	47	46	45	44	43	42	41	40	39	38	37	EW3
	48	47	46	45	44	43	42	41	40	39	38	EW4
Acoustic	55	54	53	52	51	50	49	48	47	46	45	EW5 or EW1R
Insulation	56	55	54	53	52	51	50	49	48	47	46	EW2R or EW3R
	57	56	55	54	53	52	51	50	49	48	47	EW4R
Factor	58	57	56	55	54	53	52	51	50	49	48	EW6
	59	58	57	56	55	54	53	52	51	50	49	EW7
	61	60	59	58	57	56	55	54	53	52	51	EW5R
	63	62	61	60	59	58	57	56	55	54	53	EW8 or EW6R
	64	63	62	61	60	59	58	57	56	55	54	EW7R

Note: Where the calculated percentage wall area is not presented as a column heading, the nearest percentage column in the table should be used.

Source: National Research Council, Ottawa, November 1976.

Explanatory Notes:

- 1) EW1 denotes exterior wall as in Note 2), plus sheathing, plus 3/4" wood siding or metal siding and fibre backer board.
EW2 denotes exterior wall as in Note 2), plus rigid insulation (1" to 2"), and 3/4" wood siding or metal siding and fibre backer board.
EW3 denotes simulated mansard with structure as in Note 2), plus sheathing, 2" x 4" framing, sheathing, and asphalt roofing material.
EW4 denotes exterior wall as in Note 2), plus sheathing and 3/4" stucco.
EW5 denotes exterior wall as in Note 2), plus sheathing, 1" air space, 4" brick veneer.
EW6 denotes exterior wall composed of 1/2" gypsum board, rigid insulation (1" to 2"), 4" back-up block, 4" face brick.
EW7 denotes exterior wall composed of 1/2" gypsum board, rigid insulation (1" to 2"), 6" back-up block, 4" face brick.
EW8 denotes exterior wall composed of 1/2" gypsum board, rigid insulation (1" to 2"), 8" concrete.
- 2) The common structure of walls EW1 to EW5 is composed of 1/2" gypsum board, vapour barrier, 2" x 4" studs, and 2" (or thicker) mineral wool or glass fibre batts.
- 3) R signifies the mounting of the interior gypsum board on resilient clips.
- 4) An exterior wall conforming to rainscreen design principles and composed of 1/2" gypsum board, 4" concrete block, rigid insulation (1" to 2"), 1" air space, and 4" brick veneer has the same AIF as EW5.
- 5) An exterior wall as described in EW1 with the addition of rigid insulation (1" to 2") between the sheathing and the external finish has the same AIF as EW3.

Table V.2.D.6.B.: Acoustic Insulation Factor (AIF) for Various Types of Exterior Wall

Acoustic Insulation Factor	Ceiling-roof Combination
44	C1
47	C1R
50	C2 or C1DR
52	C3
53	C2D
55	C2RD

Source: National Research Council, Ottawa, September 1975

Explanatory Notes

- 1) C1 denotes $\frac{1}{2}$ " gypsum board, 3" mineral wool batts, flat roof joist and beam construction, built-up roofing.
- C2 denotes $\frac{1}{2}$ " gypsum board, 3" mineral wool batts, typical wood roof truss with ventilated attic, sheathing and asphalt roofing.
- C3 denotes paint finish, 6" concrete slab, 2" rigid insulation, built-up roofing.
- 2) R signifies mounting the gypsum board on wood strapping or resilient clips.
- DR signifies the addition of a second layer of $\frac{1}{2}$ " gypsum board mounted on resilient clips.
- D signifies the addition of a second layer of $\frac{1}{2}$ " gypsum board.

Table V.2.D.6.C.: Relates Various Ceiling-roof Construction to AIF

Percentage of total door area to total floor area of room										Exterior
<u>4</u>	<u>5</u>	<u>6.3</u>	<u>8</u>	<u>10</u>	<u>12.5</u>	<u>16</u>	<u>20</u>	<u>25</u>		<u>Door Type</u>
33	32	31	30	29	28	27	26	25		D1
37	36	35	34	33	32	31	30	29		D2
39	38	37	36	35	34	33	32	31		D3
40	39	38	37	36	35	34	33	32		D4
41	40	39	38	37	36	35	34	33		D5
42	41	40	39	38	37	36	35	34		D1 - sd
45	44	43	42	41	40	39	38	37		D2 - sd
47	46	45	44	43	42	41	40	39		D3 - sd
48	47	46	45	44	43	42	41	40		D4 - sd
49	48	47	46	45	44	43	42	41		D5 - sd
51	50	49	48	47	46	45	44	43		D3 - D3
53	52	51	50	49	48	47	46	45		D5 - D5

Note: Where the calculated percentage door area is not presented as a column heading, the nearest percentage column in the table should be used.

Source: National Research Council, Ottawa, November 1976.

Explanatory Notes:

- 1) All prime doors must be fully weatherstripped.
- 2) D1 denotes 1 - 3/4 in. hollow core wood door (up to 10% of area glazed).
D2 denotes 1 - 3/4 in. glass-fibre reinforced plastic door with foam or glass-fibre insulated core (up to 5% of area glazed).
D3 denotes 1 - 3/4 in. solid slab wood door.
D4 denotes 1 - 3/4 in. steel door with foam or glass-fibre insulated core.
D5 denotes 1 - 3/4 in. solid slab door.
- 3) Except as noted specifically above, doors shall not have inset glazing.
- 4) sd denotes storm door. The AIF values apply when the glazed sections are closed.

Table V.2.D.6.D.: Acoustic Insulation Factor for Various Types
of Exterior Doors

- (iii) In the case of a commercial development or industrial building having office space, the Noise Pollution Control Section advises that the AIF computed for "other rooms" as above be reduced by 5 AIF units in order to account for the decreased sensitivity of offices as compared to living rooms (as discussed in lecture V.5.A.)
- (e) In the case of road and rail traffic noise, the required Acoustic Insulation Factor for an exterior wall can be obtained using the appropriate section of Table V.2.D.5.
- (f) Select the appropriate types of window, exterior wall, ceiling-roof and exterior door respectively from Tables V.2.D.6.A. to V.2.D.6.D. using the obtained AIF value. Where the calculated AIF does not correspond directly to an AIF value given in the Table, the next highest AIF value should be used.

Table V.2.D.6.A. - relates various types of window to AIF. Use of the Table requires a calculation of the percentage of the total window area affecting a room to the total floor area.

Table V.2.D.6.B. - relates various types of exterior wall construction to AIF. Use of the Table requires a calculation of the percentage of total exterior wall area (less window and floors) to the total floor area.

Table V.2.D.6.C. - relates various ceiling-roof constructions to AIF.

Table V.2.D.6.D. - relates various types of exterior door to AIF. Use of the Table requires a calculation of the percentage of the total door area affecting a room to the total floor area of that room.

Where a window or exterior door type has been determined in relation to more than one room, it shall comply with the highest insulation standard so calculated.

Tables V.2.D.6.A. through V.2.D.6.D. have been compiled by the National Research Council of Canada from laboratory tests on various components. These may be revised from time to time as methods and standards of construction change, and as results of a series of field tests become available and are evaluated.

- (h) Where building components other than those selected on the basis of AIF (from Tables V.2.D.6.A. through D.) are included in the building design, it is essential to investigate whether they are acoustically equivalent. Such an evaluation will require estimation of the STC value for the proposed equivalent component and comparison to the STC value for the component selected from the appropriate Table V.2.D.6.A. through V.2.D.6.D. The proposed component is considered acoustically equivalent if its STC number is equal or greater than the STC value for the component calculated from the Tables.

V.2.D.6.2. Associated Ventilation Requirements

The AIF values are based on conventional windows and doors closed and fully weatherstripped. The effectiveness of sound insulation is considerably reduced if windows and doors are opened and left open.

Since the insulation criteria may not be met when windows are opened and in order to provide natural ventilation and remove heat build-up in the room, provision for alternative natural or mechanical means of ventilation is a basic requirement.

V.2.D.6.3. Example

A worked example is given to illustrate the method of determining the building components for adequate sound insulation of buildings. The example concerns a recently constructed commercial building, which is a typical branch bank located within the NEF 45 contour of an airport.

To determine the appropriate building components for this building, it was necessary to undertake calculations for the general banking area only. The Managers' office shown in the drawing V.2.D.13. is surrounded by office partitions and is not considered a separate room.

Acoustic Insulation Factor:

The components forming the outer envelope of the building are: wall, window, door, ceiling-roof;

Total number of components = 4

From Table V.2.D.4.

AIF = NEF - 2 + 6 = 45 + 4 = 49

To account for the decreased sensitivity in a commercial area (as discussed in V.5.A.) AIF is reduced by 5 points to AIF 44.

It is necessary at this stage to calculate the percentages (ratios) of the total window area, total exterior door area and the net exposed exterior wall area (i.e. excluding window and door areas) to the total floor area of the general banking space. The areas of each component and the respective percentages of the floor area are shown in Table V.2.D.7. below.

Component	Area of the component, ft. ²	% of floor area
Exterior walls	736	30
Windows (front and side)	835	30
Door	66	3
Roof-Ceiling	2415	100

Table V.2.D.7. Relative Size of Building Envelope Components.

The next Table V.2.D.8. gives the specification of the components of the outer envelope of the building.

Exterior walls, Table V.2.D.6.B.	EW3
Windows, Table V.2.D.6.A.	W5-W6/2" or W5-W5/3.6" WT1-W5/3"
Door, Table V.2.D.6.D.	D2-sd
Ceiling-roof, Table V.2.D.6.C.	C1

Table V.2.D.8. Specification of Building Components.

It should be noticed, that there were various alternatives open to builders and architects which would fulfill the sound insulation requirements. The following components listed in Table V.2.D.9. were proposed by the building consultant for the bank under consideration (as shown on the detail drawings V.2.D.13.). The components specified from the Tables A through D are shown in the third column of the Table for comparison.

Component	Proposed by the developer	Specified from Table A to D
Walls	4" field stones on 10" concrete block. Approx. STC 55	$\frac{1}{2}$ " gypsum board, vapour barrier, 2" X 4" studs, 2" mineral wool batts, 2" X 4" framing, sheathing, asphalt roofing material Approx. STC 39
Windows	$\frac{1}{4}$ " glass and 2" air space sealed and fixed Approx. STC 36	$\frac{1}{4}$ " glass, 2" air space, $\frac{3}{8}$ " glass sealed and fixed Approx. STC 38
Door	Double door 1- $\frac{3}{8}$ " aluminum $\frac{1}{4}$ " plate, glass with 4" air gap Approx. STC 31	1- $\frac{3}{4}$ " glass-fibre reinforced plastic door with foam insulated core, plus storm door Approx. STC 30
Ceiling-roof	4 ply felt and gravel built up roofing on 1" rigid insulation on vapour barrier, on 1- $\frac{1}{2}$ " galvanized steel deck (at least 18 lb/ft. ²) Approx. STC 45	$\frac{1}{2}$ " gypsum board, 3" mineral wool batts, flat roof joint and beam construction; built up roofing. Approx. STC 44

Table V.2.D.9. Comparison of Specified and Proposed Building Components.

It can be seen from the above comparison that walls, door and ceiling roof components proposed by the developer are acoustically equivalent and better than the components specified from the Tables. However, $\frac{1}{4}$ " glass and 2" air space, windows sealed and fixed, are acoustically weaker than the glazing specified from the Tables. The STC value for the proposed window type is 2 points lower than the specified minimum requirement. In order to comply with the minimum insulation requirements for the window there were two alternative solutions:

- (i) to specify acoustically improved windows (i.e. $\frac{1}{4}$ " glass and $\frac{3}{8}$ " glass separated by 2" air space, sealed and fixed;
- (ii) to reduce the area of glazing;

The developer finally decided to reduce the total area of glazing to 50% of its previous value and retain the proposed $\frac{1}{4}$ " glass and 2" air space glazing. Such a reduced window area would constitute 17.5% of the floor area.

According to Table V.2.D.6.A., at 17.5% of window area to total floor area for AIF 41, a $\frac{1}{4}$ " glass separated by 2" air space (having approximate STC 36) will satisfy the minimum insulation requirements.

Thus, it can be concluded that also the proposed glazing, featuring STC 36, will be an acoustically equivalent component.

SUBJECT:
ACOUSTICS TECHNOLOGY IN
LAND USE PLANNING

TOPIC: V.3.A.
MEASUREMENT OF SOUND
WITH A SOUND LEVEL METER

OBJECTIVES:

Trainee will be able to:

1. Operate the controls on a simple sound level meter;
 2. Operate a sound level meter calibrator;
 3. Calibrate the sound level meter for pressure amplitude;
 4. Take measurements of sound levels with regard to proper measurement techniques;
 5. Review the range of instrumentation available for environmental noise investigations.
-

V.3.A. MEASUREMENT OF NOISE

V.3.A.1. SOUND LEVEL METERS

The make and type of meter described below is not necessarily endorsed by the Ministry. It simply represents one of the common types in current use others being shown in Figure V.3.A.1.

V.3.A.1.1. Bruel & Kjaer Type 2205 Sound Level Meter

The 2205 sound level meter is a general purpose instrument and is designed to make sound level measurements in the field (shown in Figure V.3.A.1.a). It is simple to use and requires very little technical knowledge to operate.

This meter is equipped with a 1" diameter piezoelectric microphone.

It has a dynamic range of 32 dB to 140 dB. A, B, and C weighting networks are included.

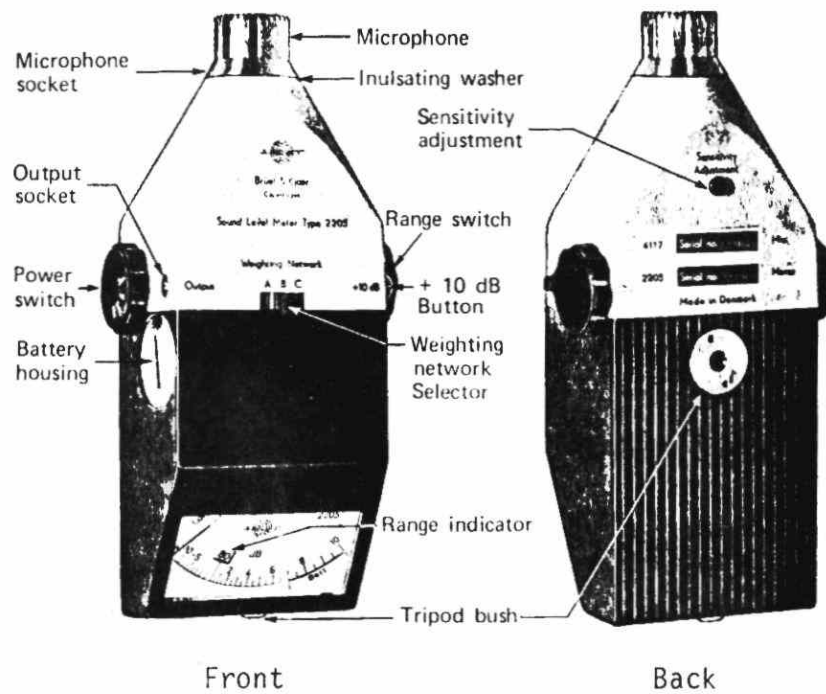
V.3.A.1.2. Operation of Controls

Range Switch: This switch selects the sound level range indicated by the meter. It has ten positions (30 to 120 dB in 10 dB steps) which are displayed at the small window close to the "zero" of the meter scale. The reading at this window gives the magnitude of the scale zero. For example, when the meter indication is 6 and the range reading is 80 dB, the sound level at the microphone is 86 dB (when +10 dB button is not depressed).

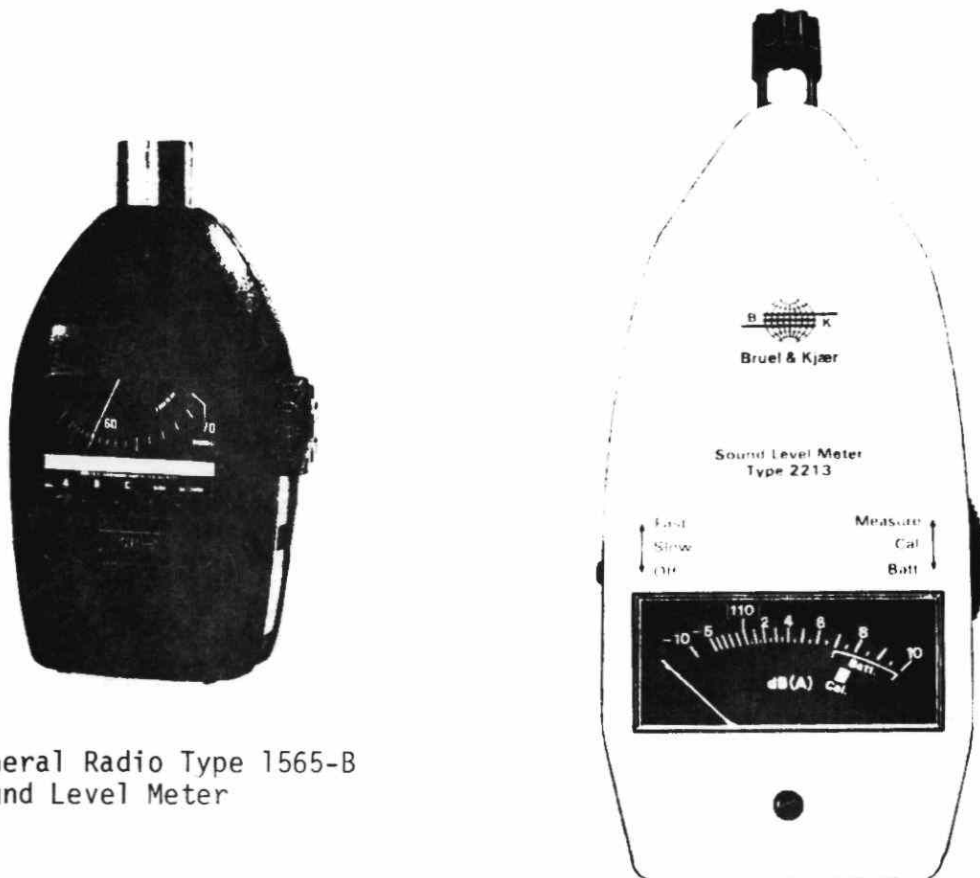
Weighting Network Selector: Any one of the A, B, or C weighting networks can be selected using this sliding switch.

Power Switch: Operation of this knob is the first step when using a sound level meter. Before moving this switch from the OFF position, set the range switch to 120 dB position. This is to protect overloading of the meter. The range switch is then gradually turned until a reasonable deflection is observed on the meter.

Other positions of the switch are outlined below:



(a) Bruel & Kjaer Type 2205 Sound Level Meter



(b) General Radio Type 1565-B Sound Level Meter

(c) Bruel & Kjaer Type 2213 Sound Level Meter

Figure V.3.A.1.: Examples of General Purpose Sound Level Meters

BATT: Switching to BATT gives a check on the condition of the battery. A meter deflection within the region marked "BATT" indicates that the battery is in satisfactory condition. This deflection is independent of the setting of the range switch. This switch position enables a quick check of the battery at any time.

FAST or SLOW: These positions enable selection of fast or slow meter response during noise measurements.

+10 dB BUTTON: When held depressed, this button switches the range of the instrument upwards by 10 dB. This button is used when noise being measured exceeds the maximum meter reading on the scale, and not enough time is available to set the range switch to the next range position. For example if measuring a 95 dB sound when the range switch is set at 80 dB will give full scale indication on the meter. By holding depressed +10 dB button the range is instantly changed to 90 dB. Now the needle will indicate a reading of 5 dB on the meter.

SENSITIVITY ADJUSTMENT: This adjustment is operated by a small screwdriver for matching the meter indication to the calibration signal.

TRIPOD BUSH: Provided at the back of the instrument, this is used to mount the instrument on an ordinary photographic tripod during long periods of measurement.

Another sound level meter with similar capabilities is the General Radio type 1565-B, as well as the new Bruel & Kjaer Type 2213. See Figure V.3.A.1.(b) and (c).

V.3.A.2. CALIBRATORS

Calibrators are used in conducting calibration checks on sound level meters. Different types and makes of calibrators are available on the market with a wide range of prices. It should be noted that the example below represents a typical instrument available on the market and does not necessarily constitute endorsement of the make or the model by this Ministry.



(a) Bruel & Kjaer Type 4230 Sound Level Calibrator



(b) 4230 Calibrator Fitted on 2205 Sound Level Meter

Figure V.3.A.2.: A Typical Sound Level Calibrator

V.3.A.2.1. Bruel & Kjaer Type 4230 Sound Level Calibrator

This is a portable, lightweight acoustic calibrator (See Figure V.3.A.2.(a). It fits all Bruel & Kjaer microphones of 1" as well as $\frac{1}{2}$ " (with an adaptor installed) diameter.

V.3.A.2.2. Operation of Calibrator

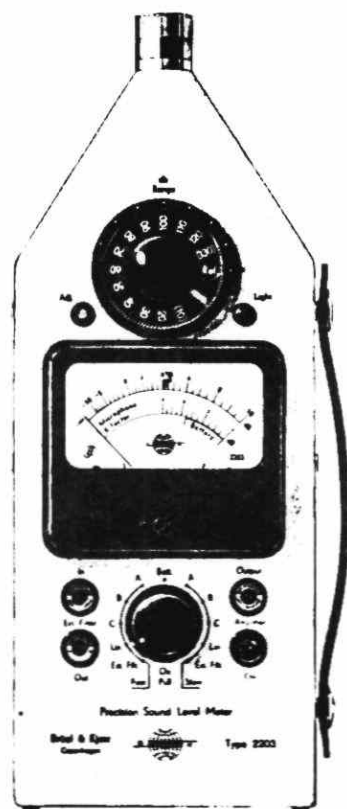
By pressing the button on the calibrator, a 1KHz tone of 94 dB will be produced and last for 60 seconds or longer. If the tone lasts only a few seconds after pressing the button, the battery should be replaced. When the calibrator is fitted to a 1" microphone, a 1KHz tone of 93.6 dB is produced when the calibrator button is depressed (93.8 dB for $\frac{1}{2}$ " microphone).

V.3.A.2.3. Calibration of a B & K 2205 Sound Level Meter

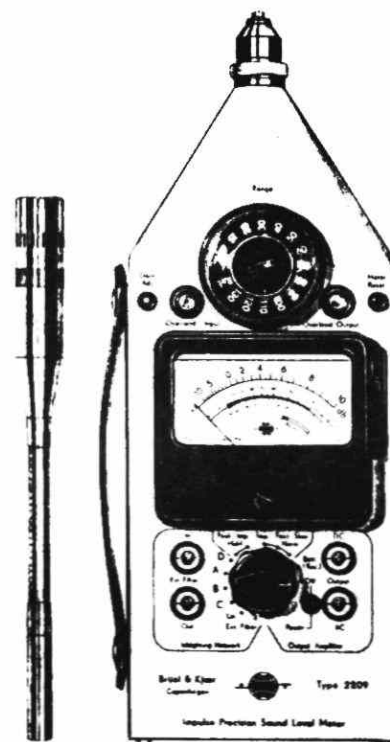
The microphone of the sound level meter to be calibrated is fitted into the cavity (coupler) provided in the calibrator as shown in Figure V.3.A.2.(b).

The power switch on the sound level meter is turned to "BATT". If the meter needle deflects into the region marked "BATT", the battery is in satisfactory condition. If not, replace the battery.

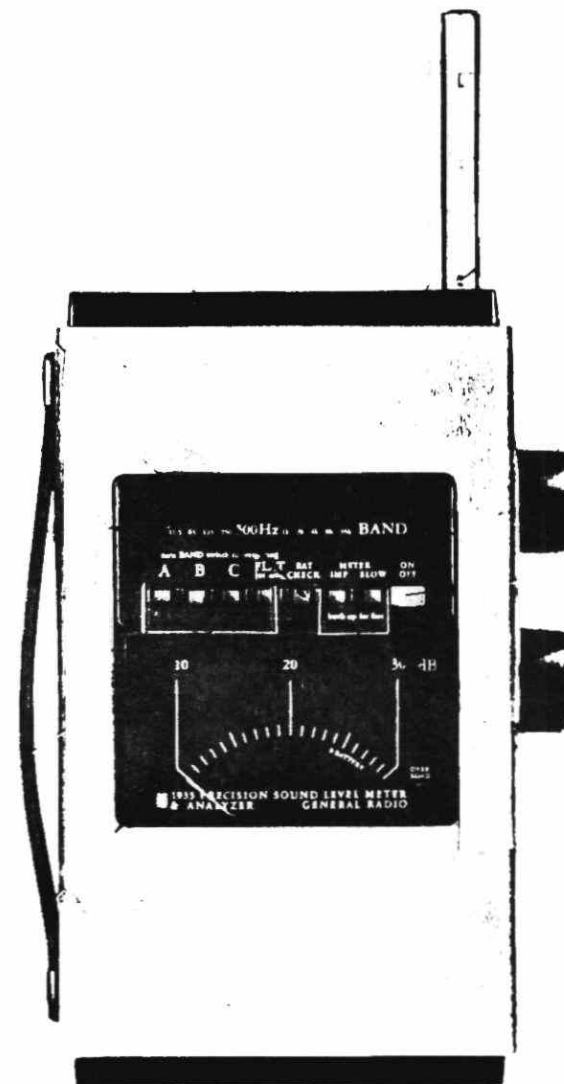
Then set the power switch to "FAST", and the range switch to 90 dB. Press the calibrator button and the meter needle should indicate 3.6 dB for the 1" diameter microphone. If it does not, insert a small screwdriver in the cavity on the back of the sound level meter marked "Sensitivity Adjustment", and carefully turn the screwdriver until the meter needle reads 3.6 dB. At the end of this procedure, remove the calibrator and record the dB reading. The sound level meter is now calibrated, and can be used for noise measurements. The calibration procedure should be repeated when the noise measurements are completed and the dB reading noted and recorded.



(a) B & K Precision Sound Level Meter Type 2203



(b) B & K Impulse Precision Sound Level Meter Type 2209



G.R. Type 1933 Precision Sound Level Meter

Figure V.3.A.3.: Examples of Precision Sound Level Meters

V.3.A.2.4. Accuracy:

The accuracy of calibration is better than ± 0.5 dB between 0 and 50⁰ C.

V.3.A.3. MEASUREMENT TECHNIQUES

The following discussion will help in obtaining reliable outdoor sound measurements.

V.3.A.3.1. Effect of Background Noise

To accurately measure an outdoor noise source the background level in the area should ideally be more than 10 dB lower than when the source is operating. Then, the noise level of the source is simply the measured level. For example, the measured level from an industrial fan is 66 dBA. The actual sound level of the fan will be 66 dBA.

If, in the above example, the background level is 56 dBA or higher (the difference being less than 10 dB) measurements are best avoided. Sometimes, by rescheduling the measurements this difficulty can be overcome. If the background level drops to 55 dBA or lower at the site, then measurements could be made without adjustments.

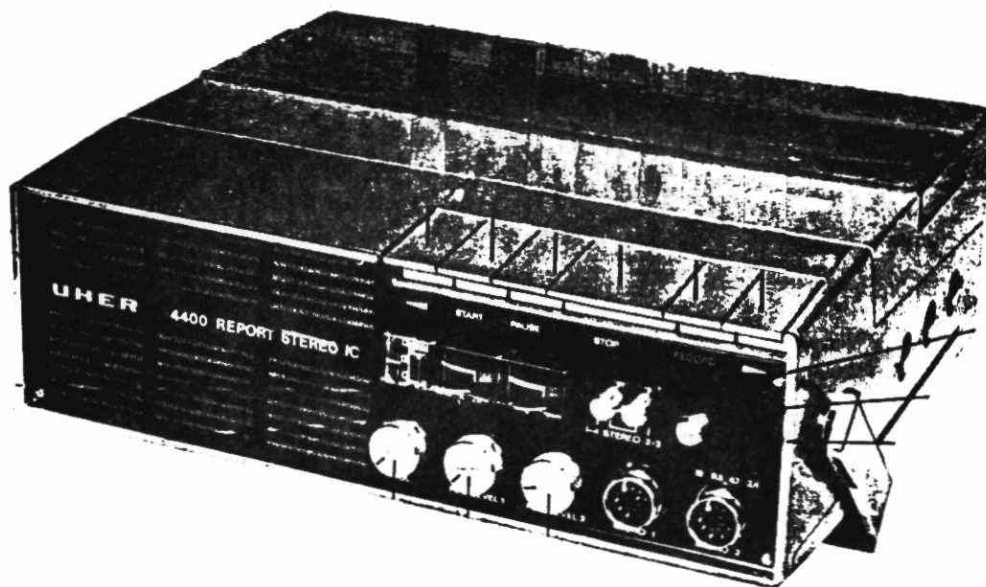
V.3.A.3.2. Meteorological Parameters

Sound measurements should not be made outdoors when the following meteorological conditions exist:

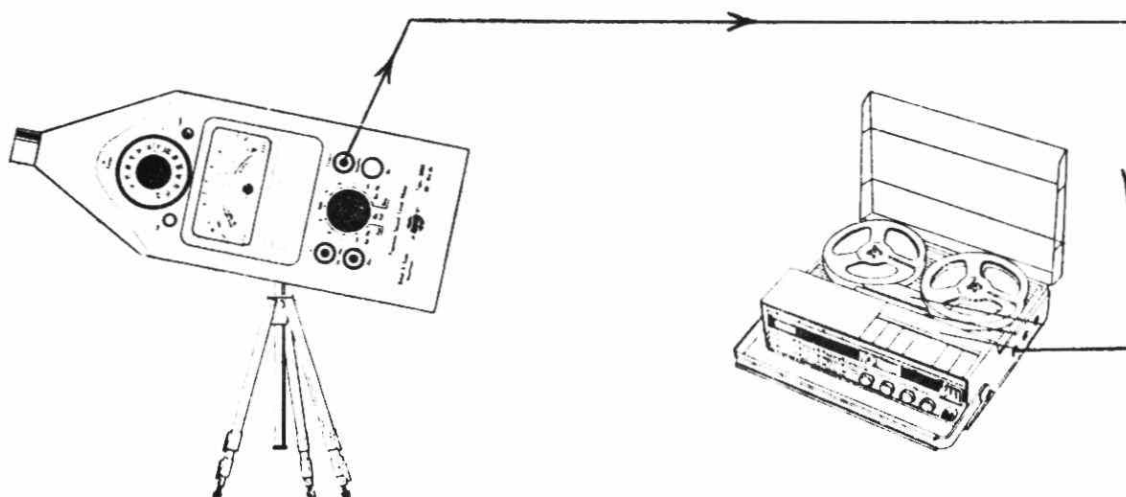
1. Wind speed, in excess of 12 mph;
2. Temperature; outside the range -10⁰C to 50⁰C (14⁰F to 122⁰F);
3. Humidity; relative humidity exceeds 90%.

High wind speeds generate turbulence around the microphone. The turbulence causes pressure fluctuations in this region which the microphone senses as sound. This "pseudo sound" is often of sufficiently high level to mask the actual noise under investigation.

Care should be taken not to make sound measurements in conditions where the temperature is beyond the meter specifications. The temperature range of operation of the meter is usually quoted in the instruction manual, and sound measurements should not be taken outside this range.



(a).: Uher 4200 Report Stereo IC Tape Recorder



(b).: Set-up for Recording Noise Signal Using B & K SLM and UHER Tape Recorder

Figure V.3.A.4.: An Example of Noise Recording Equipment

High humidity conditions can also make the measurement of sound inadvisable. Most meters are not to be used if the humidity exceeds 90%. If condenser microphones are being used, moisture can condense between the diaphragm and backplate making measurements unreliable.

It is good practice to note the wind direction, as the propagation of sound in air can be strongly affected by meteorological conditions, especially immediately above the ground.

V.3.A.3.3. Reflecting Surfaces

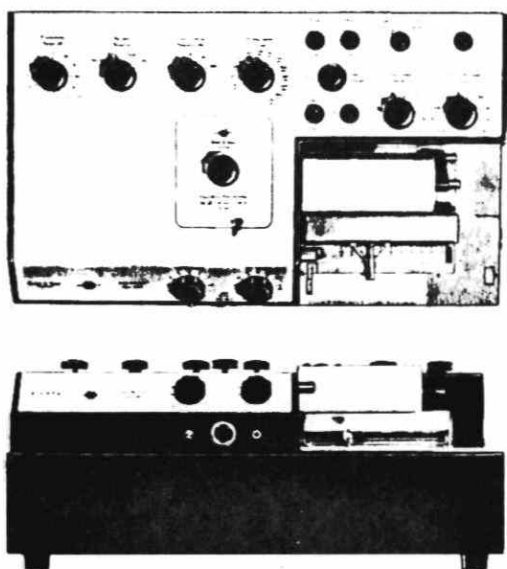
When measuring outdoor noise sources, the presence of walls, obstructions and even the sound level meter operator, can affect the sound field of the source. The disturbance in sound field can cause incorrect measurements. These errors are most marked in the frequency range of 200 - 4000 Hz, when the physical dimensions of objects are similar to, or larger than, the wavelength of the sound. Errors up to 6 dB may be experienced because of the presence of the operator.

The most effective way to avoid these errors is to select measurement sites which are level, clear and far removed from any reflecting surfaces. In order to reduce errors due to the presence of the operator, the sound level meter may be attached to the pistol grip and held at arm's length during the measurement.

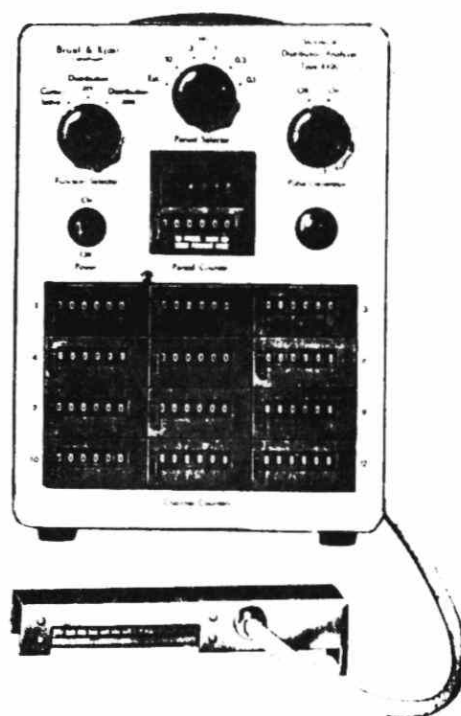
V.3.A.3.4. Aiming of Microphones during Measurements

There are two types of microphones used in sound measurements. The first type of microphone should be pointed towards the sound source if the sound field is estimated to be coming from one direction. This is known as a flat perpendicular-incidence response type and the IEC (International Electrotechnical Commission) standards for microphones apply to them. B & K 2205 sound level meter is equipped with this type of microphone (B & K type 4117).

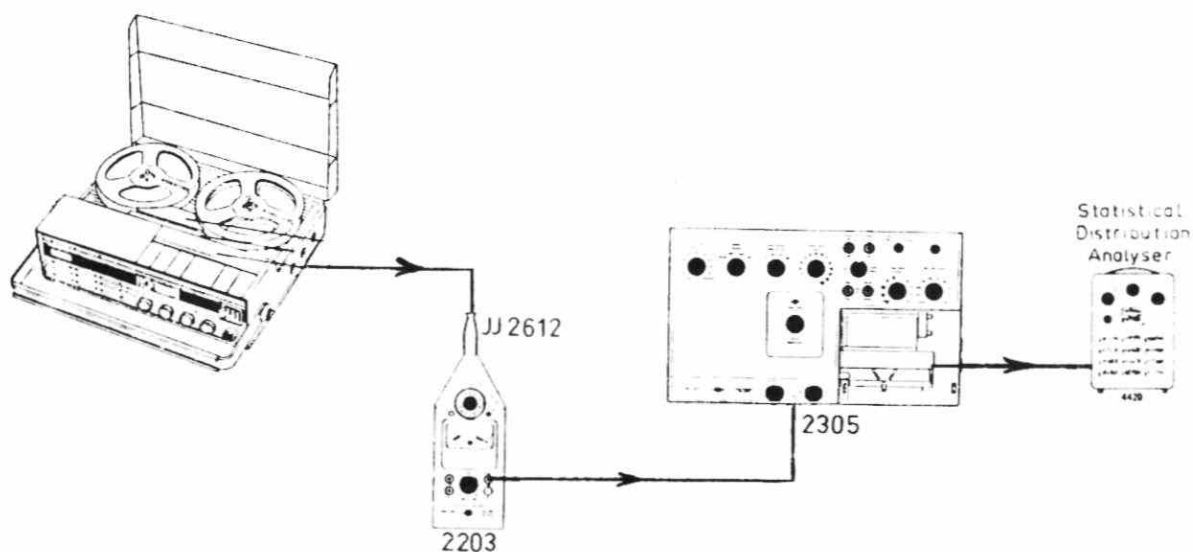
Microphones known as flat random-incidence response types should be held so that sound from the source grazes the diaphragm.



(a) B & K Level Recorder Type 2305



(b) Statistical Distribution Analyzer Type 4420



(c) Typical Set-up for Performing Statistical Analysis of Pre-recorded Noise.

Figure V.3.A.5.: An Example of Noise Analysis Equipment

V.3.A.3.5. Recording Sound Level Measurements

The meter needle fluctuates when measuring unsteady noises. In such instances, the range of fluctuations is recorded. For example, if the needle reading fluctuates between 64 and 67 dBA, the range of 64 to 67 should be recorded rather than the average reading of 65.5 dBA.

V.3.A.4. REVIEW OF ENVIRONMENTAL NOISE INSTRUMENTATION

V.3.A.4.1. Precision Sound Level Meters

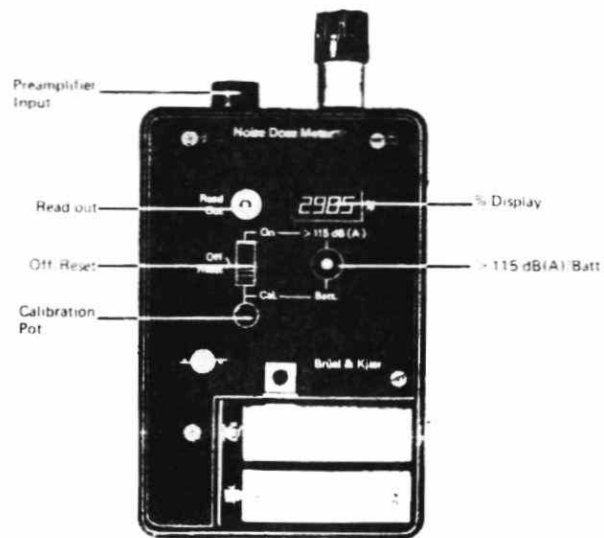
Figure V.3.A.3. illustrates typical examples of Precision Sound Level Meters which are used in the Assessment of Environmental Noise. The make and type of instruments shown in this section of the manual are not necessarily endorsed by this Ministry. Further details on these instruments may be found in the course manuals for Environmental Acoustics Technology I and II prepared by this Ministry.

V.3.A.4.2. Tape Recorders in Noise Analysis

In many cases of noise measurement, it is convenient and sometimes necessary to be able to record and store the original noise signal for reproduction and analysis later in the laboratory.

A tape recorder is a very useful instrument in the processing of noise signals. Some typical applications of a tape recorder in acoustical signal analysis are the following:

- Measurement and evaluation of impulsive noise, transient or intermittent noise, and various types of stationary noise.
- Continuous repetition of transient signals for frequency analysis.
- Automatic operation in association with a time clock or sound level trigger, thereby making it unnecessary to have a person continuously attending and reading a sound level meter. (A sound level trigger is a circuit which switches the recorder "ON", when the sound level reaches a pre-set value).



(a) The Noise Dose Meter with protection cover removed



(b) Assembly with the Microphone Preamplifier ZE 0132

Figure V.3.A.6.: B & K Type 4424 Noise Dose Meter

- A tape recorder such as shown in Figure V.3.A.4.(a) is easily transportable, making it possible to perform a subsequent analysis of the sound in the laboratory when the analysis equipment itself cannot conveniently be taken to the original site of the noise event. Further details on the basic operation, etc., of tape recorders, may be found in the course manual for "Environmental Acoustics Technology II" prepared by this Ministry.

V.3.A.4.4. An L_{eq} Measurement System

Since the equivalent energy sound level, L_{eq} (see Topics V.1.C. and V.1.D.), is the leading descriptor defining sound level limits as set by the Noise Pollution Control Section, a brief description of typical instruments which can provide the L_{eq} level in dBA follows:

- (a) B & K 2305 Level Recorder (See Figure V.3.A.5.(a)) and B & K 4420 Statistical Distribution Analyzer (See Figure V.3.A.5.(b))

The recorded noise sample is played back using a tape recorder and passed to a sound level meter, the microphone of which has been replaced by an adapter. The sound level meter is used to 'A'-weight and amplify the tape recorded sample. From the sound level meter, the signal is passed to a level recorder, the pen of which traces out the variation of the noise level on a roll of calibrated paper. Mounted on the pen is a slider which moves over a set of 12 electrical contacts. Each time the pen passes a contact, a pulse is passed to a statistical distribution analyzer which counts the number of times the pen passes each of the 12 contacts. As the contacts correspond to a sound level interval of 5 dB, this process is equivalent to splitting the time varying sound into 5 dB wide bands (5 dB windows).

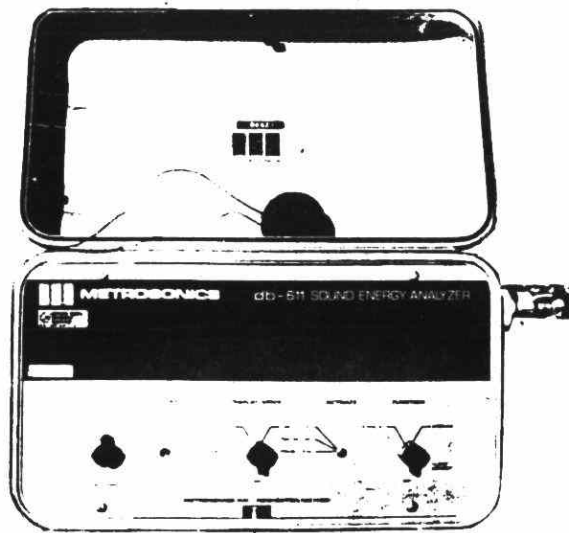


Figure V.3.A.7.: Metrosonics db-611 Sound Energy Analyzer

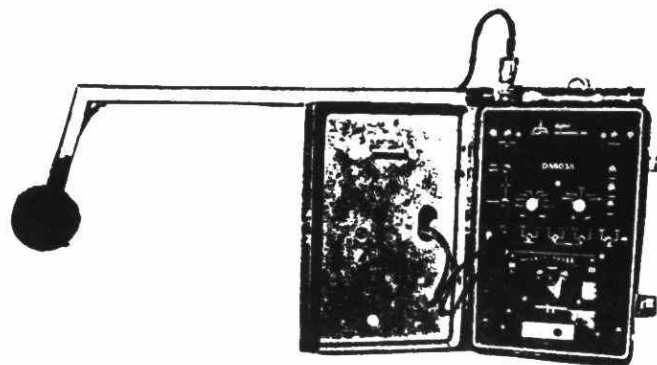


Figure V.3.A.8.: Digital Acoustics DA 603A Sound Level Monitor

The statistical distribution analyzer will indicate how long the pen remained in each 5 dB band. At the end of the analysis period, the numbers registered on the 13 counters (12 channel counters plus one total counter) are noted, and then used to determine the value of L_{eq} or other sound level descriptors. The experimental arrangement is illustrated in Figure V.3.A.5.(c). Further details on the operation, etc. of the level recorder and statistical distribution analyzer may be made to the course manual for Environmental Acoustics Technology III prepared by this Ministry.

- (b) In addition to the foregoing tape recorder method which stores the data in analogue format on the tape for eventual analysis in the laboratory, the newer recording devices provide the data in digital format, some equipped to read out the L_{eq} level on the site of measurement, and others requiring analysis in the laboratory. Examples of instruments which provide on-site read-out of L_{eq} are the B & K Model 4424 Noise Dose Meter and the Metrosonics db-611 Sound Energy Analyzer. An example of those requiring laboratory analysis is the Digital Acoustics DA603A Sound Level Monitor. A brief description of these instruments follows:

(i) Noise Dose Meter

Commonly called the Dosimeter, it is small, lightweight, and easy to use. This instrument is modified (by inserting a 30 dB preamplifier between the microphone and the instrument) from the personal dose meter which is worn by an industrial worker, for example, to determine if the worker is exposed to noise levels exceeding those set out in The Industrial Safety Act, 1971.

By carefully noting the period of time for which the dosimeter was summing the noise energy, and noting the number displayed at the end of the monitoring period, the L_{eq} is easily determined from a pocket-size chart supplied by the manufacturer.

Noise Instrumentation	Simple to Use	Light Weight	Operator Required in Attendance During Monitoring	Adjustable Sampling Rate	A Record of All Noise Samples Taken During Monitoring	On-Site dB(A) Read-Out	On-Site Leg Read-Out
B & K 2203 Sound Level Meter and UHER 4200 Tape Recorder	No	Yes	Yes	Continuous	Yes (Reel Tape)	Yes	No (Must Use Level Recorder and Statistical Analyzer in the Laboratory)
Digital Acoustics DA603A Sound Level Monitor	Yes	Yes	No	Yes	Yes (Digital Cassette Tape)	Yes	No (Must Use DA604A Cassette Reader and Calculator in Laboratory)
B & K 4424 Noise Dose Meter (Dosimeter)	Yes	Yes	Yes	No	No	No	Yes
Metrosonics dB-611 Sound Energy Analyzer	Yes	Yes	Yes	Yes	No	Yes	Yes

Table V.3.A.1.: Significant features of On-Site Environmental Noise Instrumentation
(Demonstrated in the Workshop)

(ii) Sound Energy Analyzer (Metrosonics Model db-611)

This instrument is light in weight, easy to use, and is enclosed in a weather proof container. Like the Dosimeter, it sums the sound energy received at the microphone; however it is more versatile as it is equipped with its own clock to provide the time factor which is essential for determining the L_{eq} . The L_{eq} or instantaneous reading of the sound level can be read easily from the display register.

(iii) Digital Acoustics DA 603A Sound Level Monitor

This Unit is portable and weatherproof and is suitable for recording sound levels unattended for several days. The sound levels are recorded digitally on a tape cassette. The cassette must be returned to the laboratory for analysis by a Cassette Reader and Programmable Calculator. The print out from the calculator can contain the values of the sound level descriptors from L_1 to L_{99} as well as L_{eq} . (Illustrations of these items of digital equipment are provided in Figures V.3.A.6., V.3.A.7. and V.3.A.8.

SUBJECT:
ACOUSTICS TECHNOLOGY IN
LAND USE PLANNING

TOPIC: V.3.B.C.& D. (Workshop)
INVESTIGATION OF LAND USE
PLANNING SCHEMES

OBJECTIVES:

Trainee will be able to:

1. Use a general purpose sound level meter to obtain on-site sound level measurements;
 2. Obtain L_{eq} values of traffic noise from various measurement techniques;
 3. Associate sound levels and human response through direct experience;
 4. Evaluate land use planning concepts for noise control effectiveness;
 5. Evaluate architectural designs for noise control effectiveness.
-

V.3.B. SUMMARY OF PROPOSED ON-SITE ACTIVITIES

All trainees will be taken to various sites in Toronto to view examples of the results of architectural design/planning of residences. The sites have been selected to provide the trainees with an opportunity to observe the effects due to, and noise levels in:

- (i) developments not designed/planned with regard to noise.
- (ii) developments designed/planned with regard to noise.

Trainees, will be required to complete worksheets during the course of the day. The worksheet will require the trainee to:

- (a) describe the land use of the site visited and that of neighbouring sites;
- (b) identify existing dominant, or potentially dominant noise sources, if any;
- (c) measure noise at relevant locations using the sound level meter provided;
- (d) comment on the suitability of the designated usage of the area in the light of the noise measurement; and
- (e) describe the features of the design or plan which

EITHER could have been introduced to control noise to more acceptable levels, and indicate likely benefits (not only for noise)

OR have been introduced to control noise to more acceptable levels, and indicate the likely benefits in noise reduction (using the SLMs) and in other terms.

NOTE: Trainees are reminded that the worksheets will form part of their final assessment.

SUBJECT:
ACOUSTICS TECHNOLOGY IN
LAND USE PLANNING

TOPIC: V.4.A.& B. (Workshop)
ASSESSMENT PROBLEMS

OBJECTIVES:

Trainee will be able to:

1. Assess the noise impact from a nearby transportation facility on a site proposed for residential development;
 - by using one or more of the prediction techniques which are available to determine the noise levels due to ground transportation;
 - by comparing the predicted noise levels to the appropriate sound level limits to determine the excess above the limit.
-

SUBJECT:
ACOUSTICS TECHNOLOGY IN
LAND USE PLANNING

TOPIC: V.4.C.& D. (Workshop)
NOISE ABATEMENT MEASURES

OBJECTIVES:

Trainee will be able to:

1. Evaluate the magnitude of noise impact on various designated areas of a residential development adjacent to a transportation corridor;
 2. Analyze physical techniques capable of reducing the noise impact on the development, and investigate feasible alternatives;
 3. Evaluate the effectiveness of the proposed noise abatement measures necessary to protect outdoor recreational spaces on the site;
 4. Investigate insulation requirements for the proposed buildings, and selection of adequate building components capable of reducing outdoor noise to the recommended maximum indoor noise levels.
-

SUBJECT:
ACOUSTICS TECHNOLOGY IN
LAND USE PLANNING

TOPIC: V.5.A.
LAND USE PLANNING WITH
RESPECT TO AIRCRAFT NOISE

OBJECTIVES:

Trainee will be able to:

1. Describe how noise in the vicinity of airports is evaluated using the Noise Exposure Forecast System;
 2. Correlate Noise Exposure Forecast values with Community Response;
 3. Understand the general application of the NEF system to land use planning around airports;
 4. Describe the guideline on land use planning set by the Province of Ontario.
-

V.5.A.1. INTRODUCTION

There is a growing awareness of the noise problems associated with airport operations due to an increase in air traffic and the development of land near existing airports. Public concern about aircraft noise, as with other environmental problems, manifests itself in an increasing number of complaints and in growing public debate.

According to provisions of The National Housing Act, (NHA), the Central Mortgage and Housing Corporation (CMHC) may "cause generally such steps to be taken as it may deem necessary or advisable to promote construction of housing accommodation the development of better housing and sound community planning".

The CMHC is charged with reviewing proposals for housing submitted for financing under The Act. The policy entitled "New Housing and Airport Noise" is part of the "Site Planning Handbook". The requirements set out in the policy establish a minimum standard acceptable for financing purposes.

It should be noted that the CMHC has no authority to control the use of land for residential purposes since the authority for land use planning is vested in the provincial (and municipal) governments.

The corporation's involvement is related to the security of its direct financing, its insurance of the financing provided by approved lenders and to the quality of housing conditions encouraged by its financial support.

The Ontario Ministries of Housing and the Environment have taken into account the policies and recommendations of the CMHC document "New Housing and Airport Noise" in the preparation of the Ontario draft land use policy related to aircraft noise. They have also extended these recommendations to cover land use planning involving not only new residential development but also commercial and industrial projects near airports. The following discussion will be based largely on the CMHC recommendations with additional Ontario Provincial Government guidelines introduced as appropriate.

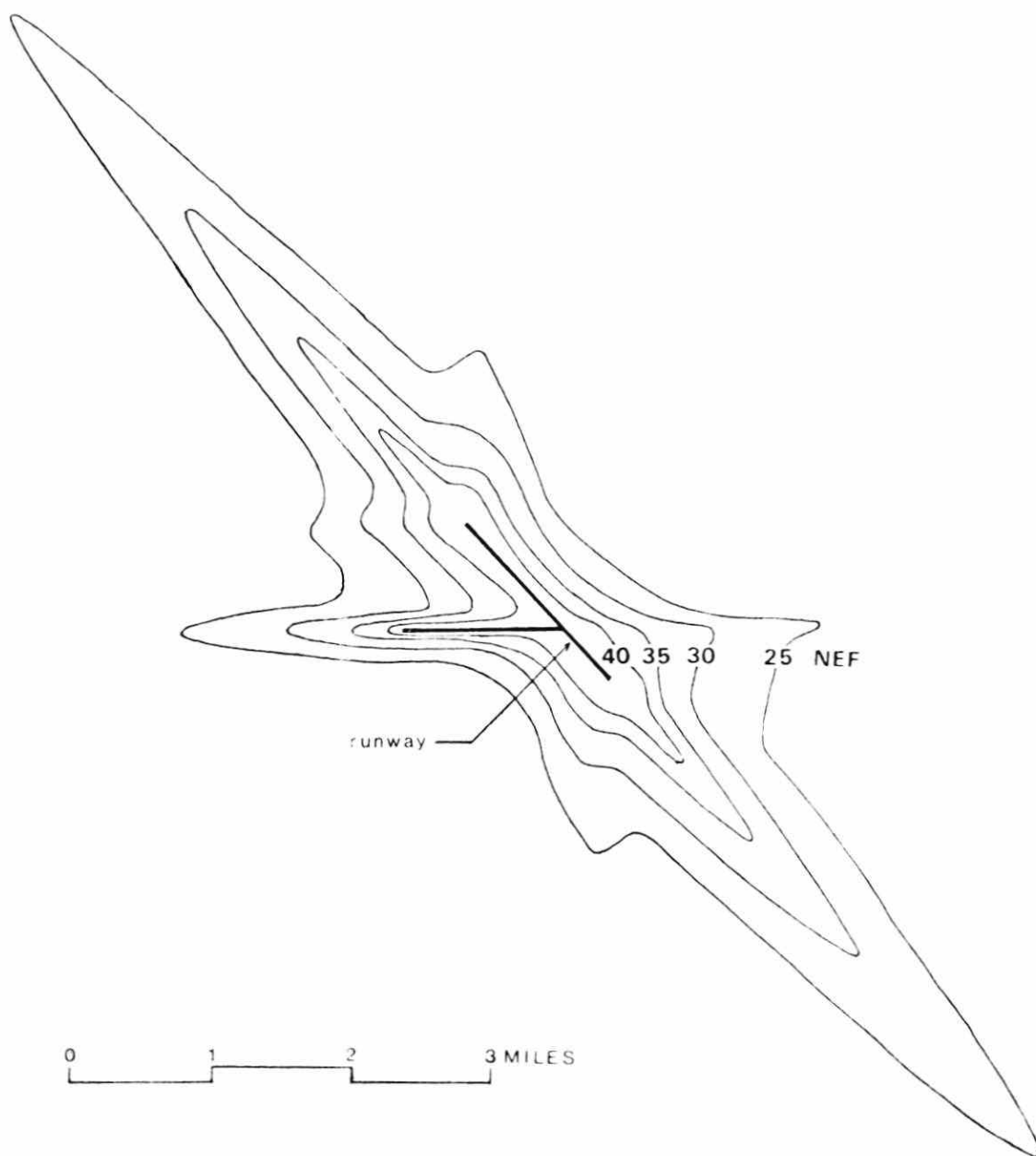


Figure V.5.A.1.: NEF Contour Map Around a Typical Airport

V.5.A.2. EVALUATION OF NOISE IN THE VICINITY OF AIRPORTS USING THE
NOISE EXPOSURE FORECAST SYSTEM

Aircraft noise can disturb sleep, privacy, rest and communication and in so doing may be considered potentially harmful to health. The long-term cumulative impact of aircraft noise on communities in the vicinity of airports, from the standpoint of causing mental or physical illness remains to be fully evaluated. However, from the weight of present evidence the Federal Department of National Health and Welfare considers that the expected noise levels within the areas where CMHC will make financing available for new construction will not cause mental or physical illness or permanent loss of hearing. In the areas where the Corporation will not make financing available, the Department considers that there is some likelihood of detrimental health effects (although this needs confirmation from additional research) and therefore agrees with the Corporation's policy of discouraging residential development in these areas.

Near airports, two sources of aircraft noise must be considered:

- (a) Flyover: flyover noise which occurs under flight paths close to airports is the most serious and common problem source. As the aircraft passes, sound waves strike the house from a progression of different directions and distances. As a result, at any particular location the noise level rises to a peak and then decreases. The noise nuisance is most acute near the ends of runways.
- (b) Ground: the noise emitted by an aircraft during ground operations, i.e. engine runup, taxiing and take-off, is less variable in direction than with flyover noise but is usually of longer duration. The noise nuisance is most acute in positions close to the runway or in the vicinity of the ground runup position.

It may be thought that the most effective alleviation of the problem of aircraft noise could be made at the source. Methods to reduce engine noise during take-off and landing operations are under constant study. Modern jet engines are being made quieter. However, no major breakthrough is expected in the foreseeable future in terms of substantial reduction in the general level of noise nuisance. For although aircraft engines may be relatively quieter in the future, the number of flights is likely to increase.

As problems caused by aircraft noise have become more acute a number of methods have been devised for evaluating noise exposure in the vicinity of airports. These methods, international in origin, are similar. They all combine many factors into a single number evaluation. The system currently used by the Federal Ministry of Transport is the Noise Exposure Forecast (NEF).

The calculation of NEF requires information about the types of aircraft using the airport and the noise they generate, the number of take-offs and landings on each runway and when these take-offs and landings occur. The noise generated by each individual aircraft type is measured in Effective Perceived Noise decibels (EPNdB).

The EPNdB value takes into account the subjectively annoying effects of aircraft noise including pure tones and duration. A summation is made of the noise (in EPNdB) from all aircraft types on all runways in calculating NEF values. The system is used primarily to develop noise contours for areas around airports, although it can be used to provide a noise exposure value for one particular location. Figure V.5.A.1. illustrates an NEF contour map for a Canadian airport of medium size. It is important to note that NEF values increase in a logarithmic manner. Thus, an increase of 10 NEF units has the effect of making the noise seem twice as loud.

The Federal Ministry of Transport has provided Noise Exposure Forecast contour maps for major airports in Canada. These maps are based upon the most up-to-date information available, and where possible, on expected future conditions. They will be revised as airport conditions change.

The Noise Exposure Forecast (in common with other aircraft noise descriptors) does suffer from certain errors. The accuracy of the NEF contours will typically be highest near the runways, and will gradually decrease with increasing distance from the runways.

NEF contours are typically based on the average operation over a year, although where there are large seasonal variations in operation, NEF contours are developed for representative seasons. In either case, the aircraft operational data (number and types) for a given time period is averaged for the time period under consideration. It must be remembered that actual operations on any given day may exhibit large departures from the averaged operational data. Therefore, judgement or analysis of aircraft noise data for any given day may not be realistic in light of such variations.

In general, NEF contours should be constructed for the average day of a year (the total volume of aircraft for a given year divided by 365), or the average day of summer months (perhaps July and August) projected for a minimum planning period of 10 years. If an existing runway is to be extended or a new runway is to be constructed in future years, the NEF contours should incorporate the anticipated changes in airport operations.

It is reasonable to assume that with reliable input data, one can predict noise exposure with an error of about ± 3 units of NEF. For situations where a large degree of uncertainty is attached to the data available on aircraft volume or runway utilization, a more realistic evaluation of the error would be some ± 5 units of NEF.

V.5.A.3. THE CORRELATION OF NEF WITH COMMUNITY RESPONSE

Individual reaction to noise, other than noise-induced hearing loss, is subjective and varies from person to person. A noise offensive to one person might not be so to another because in assessing his annoyance the individual takes into account many factors including intensity, frequency of occurrence, duration and level of background sound. Because of varied individual reactions to noise, any requirements designed to deal with the problems it causes have to be based on the viewpoint of the "reasonable" or "average" person.

The effects of aircraft noise on people and their activities may be classified under the following general headings:

1. Physiological effects, either temporary, (Examples, startle reactions and temporary hearing loss) or enduring, (Examples, permanent hearing loss or the cumulative physiological effect of prolonged sleep interference).
2. Behavioural effects involving interference with activities such as conversation, learning, TV-watching, sleep or the performance or various tasks.
3. Subjective effects, described by such words as annoyance, nuisance, dissatisfaction, disturbance, etc., as a result of behavioural and physiological effects.

The National Research Council (NRC) has analyzed many studies which have related human annoyance, complaint and speech interference to various noise ratings. Based on these studies the NRC has related Noise Exposure Forecast values to an acceptable residential environment.

Sociological surveys have indicated that adverse community reaction may start about 25 NEF. Above 30 NEF, complaints become increasingly vigorous and may be expected to take the form of concerted group action. Above 40 NEF, legal action may be expected.

The pattern of likely community reaction has been detailed by the Ministry of Transport to be shown in Table V.5.A.1.

Response Area	NEF Range	Response Prediction
1	Greater than 40	Repeated and vigorous individual complaints are likely. Concerted group and legal action might be expected.
2	35-40	Individual complaints may be vigorous. Possible group action appeals to authorities.
3	30-35	Sporadic to repeated individual complaints. Group action is possible.
4	Less than 30	Sporadic complaints may occur. Noise may interfere occasionally with certain activities of the residence.

Table V.5.A.1. Relationship between Residential Community Response

Table V.5.A.1. indicates that complaints can be expected where outdoor NEF values exceed 25. Some people, however, are prepared to live where noise exposure is above this value, particularly if their dwelling provides an acceptable indoor noise environment. While it is theoretically possible to provide sufficient insulation to achieve an acceptable indoor noise environment in an area of very high outdoor noise, there is a level above which aircraft noise seriously affects living conditions no matter how much sound insulation has been applied to the actual dwelling unit.

V.5.A.4. GENERAL APPLICATION OF THE NEF SYSTEM TO LAND USE PLANNING AROUND AIRPORTS

Figure V.5.A.2. presents the general noise assessment for various land use categories at particular NEF values. Each assessment (as quoted in "Aircraft Noise Impact - Planning Guidelines for Local Agencies", U.S. Department of Housing and Urban Development, Washington) was based on a number of factors including:

1. Speech communication;
2. Judgement of noise acceptability;
3. Need for freedom from noise intrusion;
4. Sleep interference;
5. Accumulated case histories of noise complaints experienced near airports;
6. Typical noise insulation provided by common building construction.

Different considerations are involved in determining sensitivities for different land uses and activities. Most major land uses actually involve a variety of different human activities having differing noise sensitivities. As an example, an industrial plant may encompass work areas having widely different noise sensitivities, ranging from rather stringent requirements in conference rooms and executive offices to more moderate requirements in drafting offices, general offices or typing areas. Manufacturing areas (in which noise from machinery operations creates a noise environment where high level aircraft noise intrusions would hardly be noticeable) need much less stringent requirements.

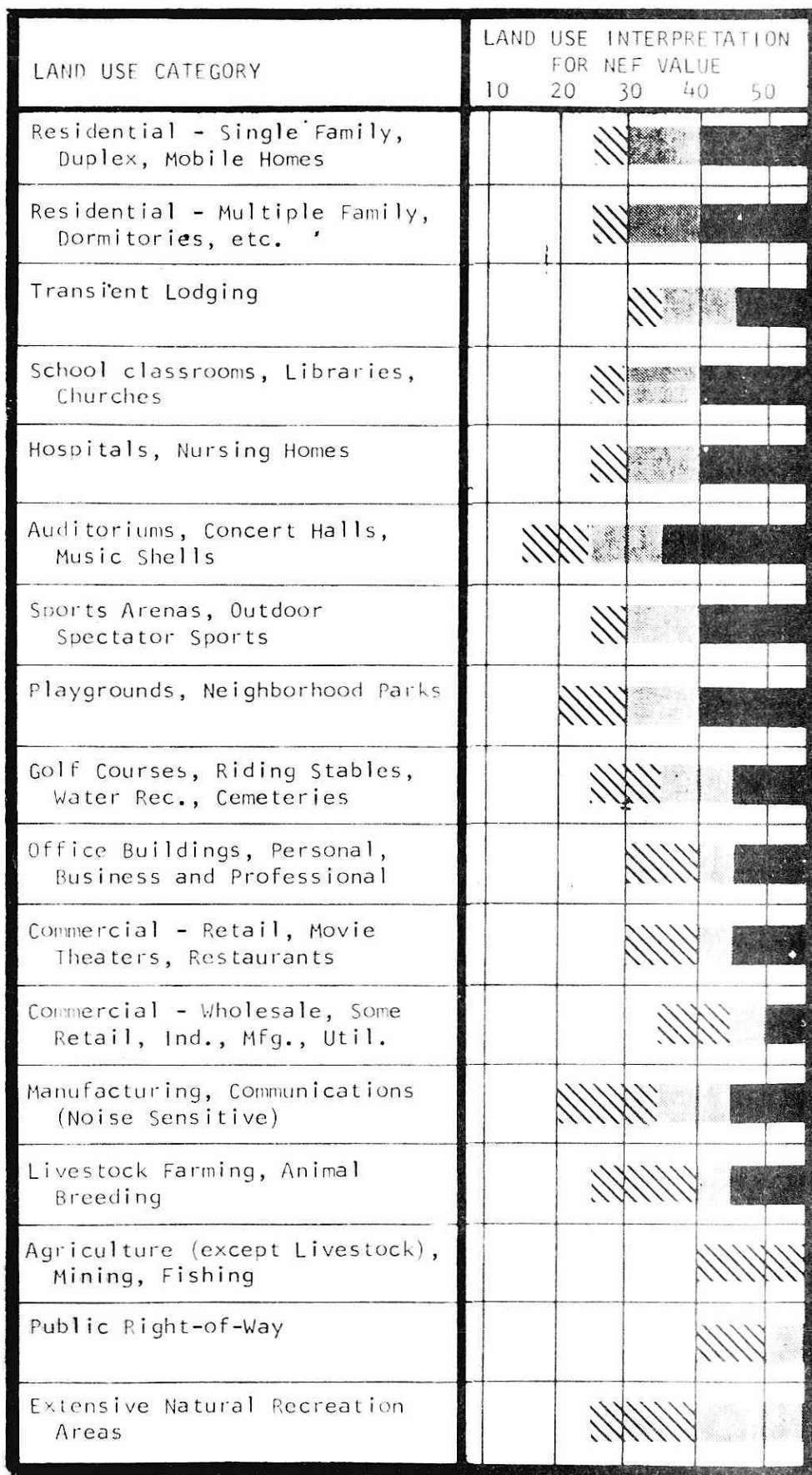


Figure V.5.A.2.: General Noise Assessment for Various Land Use Categories

It is worth considering at this stage the difference between outdoor and indoor activities. Outdoor activities are assessed in Figure V.5.A.2. by direct comparison with NEF values. As no practical noise control measures exist to control outdoor aircraft noise then problems due to aircraft noise can only be avoided by placing noise sensitive uses away from the airport and allowing only noise insensitive uses close to the airport.

For solely indoor activities however, the building structure itself can offer significant insulation against aircraft noise. Figure V.5.A.2. assumes conventional construction in the assessment of indoor uses. Special construction techniques would permit indoor activities at higher NEF values. Thus projects involving purely indoor activities can be moved closer to an airport by using special construction techniques to achieve an acceptable indoor environment.

Based particularly upon an analysis of available information with respect to scales of annoyance, complaint and the proposals and requirements of other authorities, the National Research Council advised CMHC that, with adequate sound insulation, residential development could be allowed up to the 35 NEF level. Above this the annoyance caused by aircraft noise so seriously affects the environment that residential development should not be encouraged. This upper level will remain under constant review.

Normal construction in new residential buildings should provide an acceptable indoor noise environment up to the 25 NEF level. The evidence suggests that a broad threshold exists at the 25 NEF level above which there is an ever-increasing likelihood that normal construction will be unable to provide adequate insulation against aircraft noise. The National Research Council advises that the methods suggested in the supplement for determining adequate sound insulation should be applied at the 25 NEF level and above.

The Federal Ministry of Transport advised CMHC however, that the accuracy of the NEF contours decreases with distance from the runway. While the 30 NEF contour is considered acceptable, the 25 NEF contour, because of deviations by aircraft from straight flight paths, cannot be accurately delineated. Consequently, although this contour is sometimes indicated on maps provided by the Ministry, CMHC feels unable to use it for the operation of a mandatory policy.

CMHC by reference to the appropriate Ministry of Transport NEF contour maps, has identified the following zones adjacent to airports:

- (a) an upper zone - where NEF values are greater than 35.
- (b) an intermediate zone - where NEF values are between 30 and 35 inclusive.
- (c) a lower zone - where NEF values are between 25 and 30.

V.5.A.5. ONTARIO PROVINCIAL GUIDELINES ON LAND USE PLANNING AROUND AIRPORTS

One of the major responsibilities of the Ontario Ministry of Housing is to encourage the proper planning of communities throughout the Province of Ontario. Under the provisions of The Planning Act, the Ministry of Housing is responsible for the approval of official plans, urban renewal proposals, and plans of subdivision. (The latter is the delegated responsibility of certain Regional Municipalities). The Ministry is therefore, directly involved in the process of ensuring the best possible utilization of land.

As far back as 1957, the Community Planning Branch of the, then, Department of Municipal Affairs participated in a joint study of noise associated with aircraft/airports and in particular, Toronto International Airport, Malton. The importance of aircraft/airport noise control was stressed in a statement by the Hon. W. Darcy McKeough, Minister of the Department of Municipal Affairs, regarding aircraft noise at Toronto International Airport (Malton) on October 9, 1969; The statement stressed that it is the duty of both Provincial and Local governments to ensure that the individual is protected from noise levels that might prove damaging. The statement also stressed the importance of protecting public and private investment in land and buildings as well as ensuring the full use of existing airport facilities serving local, regional, and national interests.

The overall objectives of Federal, Provincial and Municipal governments can be stated as follows:

- (i) To ensure that the effect of aircraft noise on existing built-up areas is minimized.
- (ii) To ensure that land which is affected by aircraft noise now, or in the future, is developed only with compatible uses and not for uses which will subject individuals to unacceptable noise levels.
- (iii) To inform the public so that private capital will not be invested in land which cannot be developed to its full extent because of aircraft noise.
- (iv) To ensure the future operation of existing airports to its optimum.

Recently the Ontario Ministry of Housing in close cooperation with the Ministry of the Environment has devised Draft Land Use Compatibility Tables (Appendix I) for use when considering airports where the noise is predominantly from jet aircraft. The underlying principle of the Tables is that the outdoor NEF value should take priority unless very little outdoor use will take place on the proposed development, in which case acceptable indoor noise levels should be achieved using suitable insulation techniques (CMHC guidelines as given in reference 6 of Bibliography).

It can be seen from the Tables that the three aircraft noise zones as specified by CMHC for new residential development are closely followed by the Group No. 1, "Residential etc." category.

Acceptable indoor noise levels are also based upon those supplied by CMHC. Residential development (which is taken to include hospitals, theatres, auditoriums, churches, libraries, schools and nursing homes) should be designed to achieve sound level limits advised by CMHC, which are as follows:

- (a) Indoor criteria chosen for bedrooms = -3 NEF
- (b) Indoor criteria chosen for other rooms = +2 NEF

For non-residential development, the recommended sound level limit for "other rooms" is raised by 5 NEF for private office areas, conference rooms etc. or by 10 NEF for general office areas and retail stores. The Acoustical Insulation Factors required to achieve these levels are of course decreased by the corresponding 5 or 10 NEF, as indicated under "Acoustic Design Criteria for Non-Residential Uses" of the Tables. The design of adequate sound insulation for buildings (and the concept of Acoustical Insulation Factors) is covered fully in Topic V.2.D.6. However an important point is that where glazing is relied upon to provide acceptable indoor noise levels then these windows should remain closed. To allow windows to remain closed during the summer months some form of special ventilation or air conditioning must be provided.

APPENDIX I

DRAFT

LAND USE AND AIRCRAFT NOISE POLICY

This policy supersedes the aircraft noise policy promulgated by the Minister of Municipal Affairs in October 1969, based on CNR (Composite Noise Rating) contours. The NEF (Noise Exposure Forecast) system is a noise measure providing a more accurate representation of noise annoyance than the CNR system because it takes into account the duration of the noise signals and their frequency components.

In reviewing land use proposals in the vicinity of airports, the Ontario Ministry of Housing will adhere to the attached NEF Land Use Compatibility Table, in conjunction with NEF contour maps prepared by Transport Canada.

The Land Use Compatibility Table has been designed to be in general accord with the Central Mortgage and Housing Corporation policy relating to residential development. (1) In addition, the Table provides policies with respect to non-residential uses. The general principle underlying the restrictions is that the outdoor noise level should govern the permissible use, unless the use clearly normally exists without human use of the outdoors for any extended period. An indoor use may theoretically be permissible up to almost any noise level, provided it complies with C.M.H.C. standards for acoustic insulation and ventilation. (The latter to ensure that the value of the acoustic insulation is not lost through the opening of windows). However, in practice, the insulation requirements may become significant for some uses and cost considerations may influence the design and the percentage of glass in the exterior surfaces.

(1) "New Housing and Airport Noise", N.H.A. 5059.

Programs Section, July 1977.

Ontario Ministry of Housing

N.E.F. LAND USE COMPATIBILITY TABLE

LAND USES (1)		NOISE EXPOSURE FORECAST VALUES				
		28	30	35	40	
GROUP I USES	residential, passive use park, school, library, church, theatre, auditorium, hospital, nursing home, camping or picnic area, riding stable, horse race track.	0	Discretionary Range			
	In this range, noise is not usually a problem for Group I uses.	28	All buildings must conform to Acoustic Design Criteria (2)(3).		No new Group I uses may be established in this range, except those for which the outdoor environment is irrelevant and which meet the Acoustic Design Criteria (3).	
GROUP II USES	hotel, motel, retail or service commercial, offices, athletic field, playground, stadium, outdoor swimming pool	0	30	Discretionary Range		
	In this range, noise is not usually a problem for Group II uses.		The characteristics of each proposed use must be studied and appropriate noise insulation must be incorporated into building design(3).		Group II uses may not be established beyond the 40 NEF contour unless they are adequately insulated indoor uses(3).	
GROUP III USES	industrial, warehousing, arena, general agriculture, animal breeding(4).	0		35	Discretionary Range	
			In this range, noise is not usually a serious problem for Group III uses.		Most Group III uses are permissible in this range, provided ancillary uses are adequately insulated(3).	

Notes

- (1) Uses not specifically mentioned should be compared to the uses listed, classified in the most appropriate Group and regulated accordingly.
- (2) For residential uses, refer to "New Housing and Airport Noise", N.H.A. 5059 and any amendments thereto. Acoustic design must include adequate ventilation. The developer of a residential project must undertake to inform prospective tenants or purchasers of the possible noise problem.
- (3) For non-residential uses, refer to the attached Acoustic Design Criteria.
- (4) Research has shown that most animals condition to high noise levels. However, fur farms, and any use likely to create a bird hazard, such as a feed lot or stock yard, should not be located closer to an airport than as recommended by Transport Canada in "Land Use in the Vicinity of Airports", document S-72-8.

DRAFT. Programs Section, July 1977.

ACOUSTIC DESIGN CRITERIA FOR NON-RESIDENTIAL USES

The procedure described in Section E of "New Housing and Airport Noise" may be adapted for use in determining adequate sound insulation for non-residential buildings. The Table below shows the correction factor to be used in relation to the figures in Table 2 of the C.M.H.C. handbook (page 13) in determining the Acoustical Insulation Factor for other uses. A.I.F. values corresponding to NEF values above the 35 contour may be obtained by extrapolation from the figures on Table 2, as reproduced on the following page.

TABLE OF CORRECTIONS TO TABLE 2 FOR OTHER USES

Hotel, motel	no correction
Private office area, conference room etc.	-5
General office areas, retail stores	-10

A hospital, theatre, auditorium, church, library, school or nursing home would be subject to the same requirements as a residential use.

EXAMPLE 1

The AIF for a retail store within the 30 contour, assuming the room has 3 components, would be $33 - 10 = 23$.

With reference to Table A of the C.M.H.C. handbook (page 14), assuming a window area = 30% of the floor area, the window could be a single pane of 24 oz. glass. Within the 40 contour, the AIF would be $43 - 10 = 33$ and a similar store would need sealed double glazing with 3/8" spacing.

EXAMPLE 2

A private office associated with an industrial use in the vicinity of the 45 NEF contour would have an AIF of $46 - 5 = 41$. Assuming a window area = 25% of the floor area, triple glazing would be required with 2" between panes.

TABLE 2
ACOUSTIC INSULATION FACTOR *

No. of components forming room envelope	NEF												
	25	26	27	28	29	30	31	32	33	34	35	40	45
1	23	24	25	26	27	28	29	30	31	32	33	38	43
2	26	27	28	29	30	31	32	33	34	35	36	41	46
3	28	29	30	31	32	33	34	35	36	37	38	43	48
4	29	30	31	32	33	34	35	36	37	38	39	44	49

* This is Table 2 of the C.M.H.C. handbook entitled "New Housing and Airport Noise", expanded to include NEF values above 35.

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- Model Municipal Noise Control By-Law
- Noise Pollution Control Publications
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Number	Log	Number	Log	Number	Log	Number	Log
1.0	0.00	4.0	0.60	7.0	0.85	1	0
1.1	0.04	4.1	0.61	7.1	0.85	10	1
1.2	0.08	4.2	0.62	7.2	0.86	100	2
1.3	0.11	4.3	0.63	7.3	0.86	1000	3
1.4	0.15	4.4	0.64	7.4	0.87	10000	4
1.5	0.18	4.5	0.65	7.5	0.88	100000	5
1.6	0.20	4.6	0.66	7.6	0.88	1000000	6
1.7	0.23	4.7	0.67	7.7	0.89	etc.	
1.8	0.26	4.8	0.68	7.8	0.89	10^0	0
1.9	0.28	4.9	0.69	7.9	0.90	10^1	1
						10^2	2
2.0	0.30	5.0	0.70	8.0	0.90	10^3	3
						10^4	4
2.1	0.32	5.1	0.71	8.1	0.91	10^5	5
2.2	0.34	5.2	0.72	8.2	0.91	10^6	6
2.3	0.36	5.3	0.72	8.3	0.92	etc.	
2.4	0.38	5.4	0.73	8.4	0.92		
2.5	0.40	5.5	0.74	8.5	0.93		
2.6	0.41	5.6	0.75	8.6	0.93		
2.7	0.43	5.7	0.76	8.7	0.94		
2.8	0.45	5.8	0.76	8.8	0.94		
2.9	0.46	5.9	0.77	8.9	0.95		
3.0	0.48	6.0	0.78	9.0	0.95		
3.1	0.49	6.1	0.79	9.1	0.96		
3.2	0.51	6.2	0.79	9.2	0.96		
3.3	0.52	6.3	0.80	9.3	0.97		
3.4	0.53	6.4	0.81	9.4	0.97		
3.5	0.54	6.5	0.81	9.5	0.98		
3.6	0.56	6.6	0.82	9.6	0.98		
3.7	0.57	6.7	0.83	9.7	0.99		
3.8	0.58	6.8	0.83	9.8	0.99		
3.9	0.59	6.9	0.84	9.9	1.00		

Table of Logarithms

Log	Number	Log	Number	Log	Number	Log	Number
0.00	1.0	0.60	4.0	0.85	7.0	0	1
						1	10
0.04	1.1	0.61	4.1	0.85	7.1	2	100
0.08	1.2	0.62	4.2	0.86	7.2	3	1000
0.11	1.3	0.63	4.3	0.86	7.3	4	10000
0.15	1.4	0.64	4.4	0.87	7.4	5	100000
0.18	1.5	0.65	4.5	0.88	7.5	6	1000000
0.20	1.6	0.66	4.6	0.88	7.6		
0.23	1.7	0.67	4.7	0.89	7.7		
0.26	1.8	0.68	4.8	0.89	7.8	0	10^0
0.28	1.9	0.69	4.9	0.90	7.9	1	10^1
						2	10^2
0.30	2.0	0.70	5.0	0.90	8.0	3	10^3
						4	10^4
0.32	2.1	0.71	5.1	0.91	8.1	5	10^5
0.34	2.2	0.72	5.2	0.91	8.2	6	10^6
0.36	2.3	0.72	5.3	0.92	8.3		etc.
0.38	2.4	0.73	5.4	0.92	8.4		
0.40	2.5	0.74	5.5	0.93	8.5		
0.41	2.6	0.75	5.6	0.93	8.6		
0.43	2.7	0.76	5.7	0.94	8.7		
0.45	2.8	0.76	5.8	0.94	8.8		
0.46	2.9	0.77	5.9	0.95	8.9		
0.48	3.0	0.78	6.0	0.95	9.0		
0.49	3.1	0.79	6.1	0.96	9.1		
0.51	3.2	0.79	6.2	0.96	9.2		
0.52	3.3	0.80	6.3	0.97	9.3		
0.53	3.4	0.81	6.4	0.97	9.4		
0.54	3.5	0.81	6.5	0.98	9.5		
0.56	3.6	0.82	6.6	0.98	9.6		
0.57	3.7	0.83	6.7	0.99	9.7		
0.58	3.8	0.83	6.8	0.99	9.8		
0.59	3.9	0.84	6.9	1.00	9.9		

Table of Antilogarithms



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